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FOREWORD

Presented number of Silesian University of Technology. Scientific Papers. Organization and Management Series. Presented papers contain result of researches conducted by various universities. The number consists of 36 papers.

The papers presented in the number concentrate on many topics connected with organization and management. There are in the number papers about: business analytics; innovations; brand management; tourism management; entrepreneurship; implementation of AI in business; finance management; marketing; human resource management; sustainable development; economics; logistics; risk management; waste management; healthcare management; occupational health and safety; Industry 5.0; SME's management; knowledge management; environmental management and business models.

Radosław Wolniak

ANALYSIS OF BUSINESS SERVICES SECTOR IN POLAND. CURRENT STATE AND DEVELOPMENT PERSPECTIVES FOR THE FUTURE

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Purpose: An in-depth analysis of Poland's modern business services sector in the context of the dynamic implementation and use of artificial intelligence tools and methods to automate and standardize business processes.

Design/methodology/approach: A review of relevant literature, industry-specific reports and survey on the use of AI/GenAI tools in the sector.

Findings: The analysis conducted in this study highlights the significant role the modern business services sector plays in the Polish economy—not only in terms of its contribution to national GDP but also in shaping the labor market. It is evident that the sector is undergoing a profound transformation. This shift is driven primarily by two key factors. First, the increasing maturity of Shared Service Center (SSC) organizations over the past decades has enabled them to transition from handling basic administrative tasks to managing more complex, knowledge-intensive processes. Second, the emergence of advanced technologies—particularly artificial intelligence (AI) and generative AI (GenAI)—has had a substantial impact on the sector, facilitating this evolution.

Research limitations/implications: The analysis of sector-related reports offers a broader perspective on the Shared Services landscape in Poland. The findings of this study can serve as a foundation for further, more detailed research.

Practical implications: The article makes a valuable contribution to understanding the current landscape of the Shared Services sector in Poland, highlighting future opportunities and the challenges associated with the implementation of AI/GenAI tools for business process automation. It outlines both the benefits and potential risks of adopting these technologies, while also addressing the growing competitive pressure from other countries—both within the region and globally—where labor and operational costs may be more favorable.

Originality/value: This article sheds light on the modern business services sector in Poland as it navigates the growing influence of Artificial Intelligence (AI) tools and methodologies. The study identifies the most commonly used tools for business process innovation and analyzes how industry leaders perceive the rising role of automation—whether as a risk, a challenge, or an opportunity.

Keywords: Business Process Management, AI/GenAI, process innovation, outsourcing, Shared Service Sector.

Category of the paper: Viewpoint, research paper.

1. Introduction

The market for modern business services (both SSC and BPO) appeals to a wide range of interest due to numerous advantages such as increased flexibility, lower costs, and higher quality of services provided. Companies around the world, in search of the most efficient business models, are increasingly opting to use external resources. The concepts of outsourcing, and subsequently offshoring, have contributed to cost reductions and increased operational efficiency. Entrusting the execution of non-core business processes allows companies to focus on their core activities and deliver additional value to customers. The modern business services sector is an important part of the Polish economy. It employs over 457,000 people, which accounts for approximately 7% of total employment in the enterprise sector in Poland. Its share in the national GDP has increased to 5.3%. The sector consists of a total of 1941 centers, characterized by a high level of internationalization and a global scope and scale of operations (Sektor..., 2024).

Currently, the sector is undergoing an intense transformation, entering a more mature phase of development. This involves a shift in focus from quantitative analyses (e.g., employment figures) to qualitative aspects such as productivity (value generated per employee), level of advancement (knowledge intensity in processes, so-called knowledge-intensive processes), automation, and innovation potential (capacity to create intellectual property). The type and scope of activities conducted by these organizations present an opportunity for many Polish regions to enter the sphere of innovation and modern technologies, making them attractive locations for new investments and promoting further economic development.

The purpose of this article is to characterize the modern business services market in Poland and assess its development prospects in the coming years in the context of the intensive implementation of process automation using AI/GenAI tools in these organizations. The article presents the current state of the industry and its development directions. It also highlights the importance of process management for the emergence and evolution of the shared services market, as well as its transformation — from the handling of transactional processes to the execution of innovative and knowledge-intensive tasks. A process is considered knowledge-intensive if achieving the required employee efficiency requires at least six months of training (Sektor..., 2024).

The article applies an analysis of the subject literature, industry reports, and research results related to the modern business services market. Part of the material is based on the author's own research, which will serve as the foundation for her future dissertation.

2. Development of the modern business services sector in Poland and globally in the context of BPM process management

The emergence of the concept of modern business services organizations, both in the form of Shared Services Centers (SSC) and Business Process Outsourcing (BPO), would not have been possible without the development of Business Process Management (BPM) methodology. Business process management is an approach focused on operations carried out within an organization in the context of so-called business processes—structured and measurable sets of activities designed to deliver specific value to the customer or market (Davenport, Short, 1990). BPM provides methods, tools, and techniques that enable the identification, analysis, execution, monitoring, and modification of business processes, leading to their continuous improvement throughout the process life cycle. Unlike traditional management, which focuses primarily on organizational structure, BPM places the customer of the processes and the relationships between individual activities at the center of its approach. The goal of this approach is to increase customer satisfaction and improve cross-functional collaboration in the organization (Dumas et al., 2013).

The concept of process management began to gain importance alongside the development of modern information and communication technologies. Their impact on the evolution of business processes is long-term, cumulative, and interconnected, and its progression can be divided into stages: from early and advanced automation, through cross-functional integration, to systemic optimization (Zaorska, 2008). In recent years, the intensive use of ICT technologies by enterprises, including those from traditional sectors not directly related to IT, has contributed to radical changes in their operations. These changes have included, among others, the modernization and improvement of the efficiency of process execution and entire value chains. Moreover, technological development fosters the intensification of globalization, which fundamentally alters the conditions of competition. A company's competitive position today is determined not so much by the possession of resources, but by the ability to control and use them effectively—regardless of whether they are owned by the company or not (Gottfredson, et al., 2005).

To remain competitive in the long term, companies must above all be innovative. This means the need to transform their operations by implementing new management models, introducing innovative products and services, expanding into new markets, leveraging modern technologies, and acquiring new sources of intellectual capital (Vashistha, 2006). The dynamic development of the Internet in the early 2000s significantly reduced the cost of information exchange, which enabled global companies to relocate business processes not directly related to production to countries with lower labor costs. The concepts of outsourcing, and later offshoring, contributed to cost reduction and increased efficiency in areas that—prior to the era of broadband Internet—had been beyond the reach of such activities (Zaorska, 2008). For many

companies, outsourcing has become not only a business model that enables faster expansion into new markets without the need to build competencies from scratch, but also a way to ensure the long-term innovation of their products and services (Bielewicz, Meronk, 2009). Its main advantages include the ability to significantly reduce operational costs, minimize the risks associated with technological and market changes, and streamline key processes—all of which directly contribute to increased competitiveness of the company (Zaorska, 2008). The importance of outsourcing in the operations of modern companies has taken on a new dimension, mainly due to the ability to apply it to an increasing number of non-production functions and processes—which was not possible before the development of modern information and communication technologies.

The concept of outsourcing presented in this article is often identified in the literature with offshoring, which does not reflect reality. The fundamental difference between these two terms lies in the location where tasks separated from the mother-organization's structure are carried out. Outsourcing refers to the transfer of specific tasks and processes from a company's internal structure to an external service provider operating in the same country as the client. In contrast, offshoring is the process of relocating services to another country. In this model, the separated tasks may be performed either by the company itself (internal offshoring) or by a foreign partner (external offshoring). This distinction makes it possible to identify two basic types of offshoring:

- Captive offshoring is a process in which a company establishes a foreign branch or a capital-linked subsidiary. This gives the company full control over the outsourced service processes. Within the structure of the modern business services sector in Poland, these organizations are referred to as Shared Service Centers (SSC).
- Offshore outsourcing is the process of transferring processes and tasks separated from the organizational structure to an external company with no capital ties and conducting business in another country. In the structure of the modern business services sector in Poland, these organizations are called Business Process Outsourcing (BPO) (Marcinkowska, 2015).

3. New technologies and their impact on the SSC (Shared Service Centers) sector in Poland

In order to answer the question of what technologies are used by SSC organizations, the author conducted an empirical study among 57 respondents employed in Shared Service Centers. The survey participants represented a diverse range of seniority and held different positions in their companies. Almost half of the respondents (49%) work in organizations employing between 200 and 400 people. The largest group of respondents, 61%, declared more

than five years of seniority in an organization. An analysis of the hierarchical structure showed that 32% of participants held operational positions, carrying out tasks directly in processes. Another 25% were lower-level managers, supervising the work of subordinate specialists. The most numerous group (43%) were representatives of senior management - including, among others, process managers and directors, managing directors of Shared Services Centers in Poland, as well as managers responsible for individual areas of SSC operations, such as finance.

The study was conducted using the CAWI (Computer-Assisted Web Interview) web survey method. The range of questions addressed to respondents included issues concerning the types of technologies used to implement process innovations in modern business services organizations operating in Poland. Among the most frequently indicated technologies were Robotic Process Automation (RPA) and Application Programming Interface (API). APIs enable the integration of systems and automatic data processing, making them among the technologies supporting automation.

Figure 1 shows the percentage distribution of the technologies used and their degree of polarization. Based on the data collected, there are three key artificial intelligence (AI) technologies that are currently being used to automate processes and thus operational tasks in shared service centers. The remaining 20 per cent of indications related to other technologies, including tools used for Business Process Management (BPM) analysis and management.

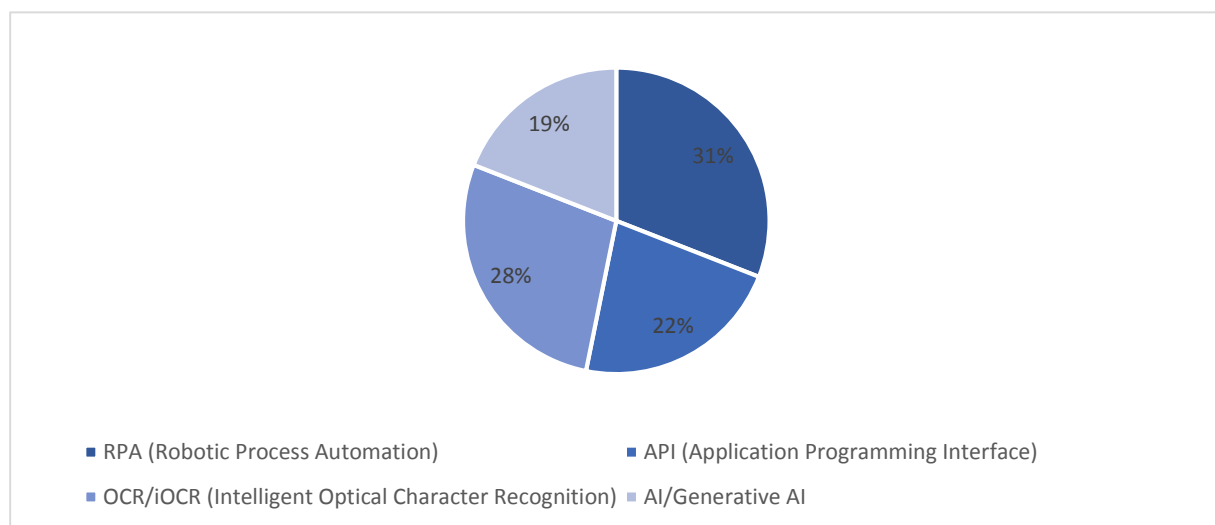


Figure 1. The most popular IAP (intelligent process automation) technologies used in business services organizations in Poland in 2024.

Source: own study.

The results of the research conducted by the author are consistent with the data presented by the Association of Business Service Leaders (ABSL), an organization representing the modern business services sector in Poland. As many as 87.5% of respondents indicated the use of RPA (Robotic Process Automation) technology, 65.6% use API (Application Programming Interface), and the third most used technology is OCR (Optical Character Recognition). Among

the less popular but important technologies categorized as Artificial Intelligence (AI), respondents indicated Process/Task Mining tools and Business Process Management Systems (BPMS) or Image Recognition Technologies (Computer Vision) and Voicebots, among others (Sektor..., 2024). According to ABSL's 2024 report, at the end of Q1 2024, 65.2% of organizations in the sector say they use intelligent process automation (IPA) in the execution of daily operational tasks, and 24.1% plan to implement it in the near future. The main reason for this high interest in process automation is to optimize costs, improve the quality and speed of services provided. Figure 2 shows the main objectives of implementing intelligent process automation (IPA) in organizations in the modern business services sector in Poland. The unprecedented driver for IPA implementation is cost optimization - indicated as a key objective for business model transformation by 60% of the surveyed organizations.

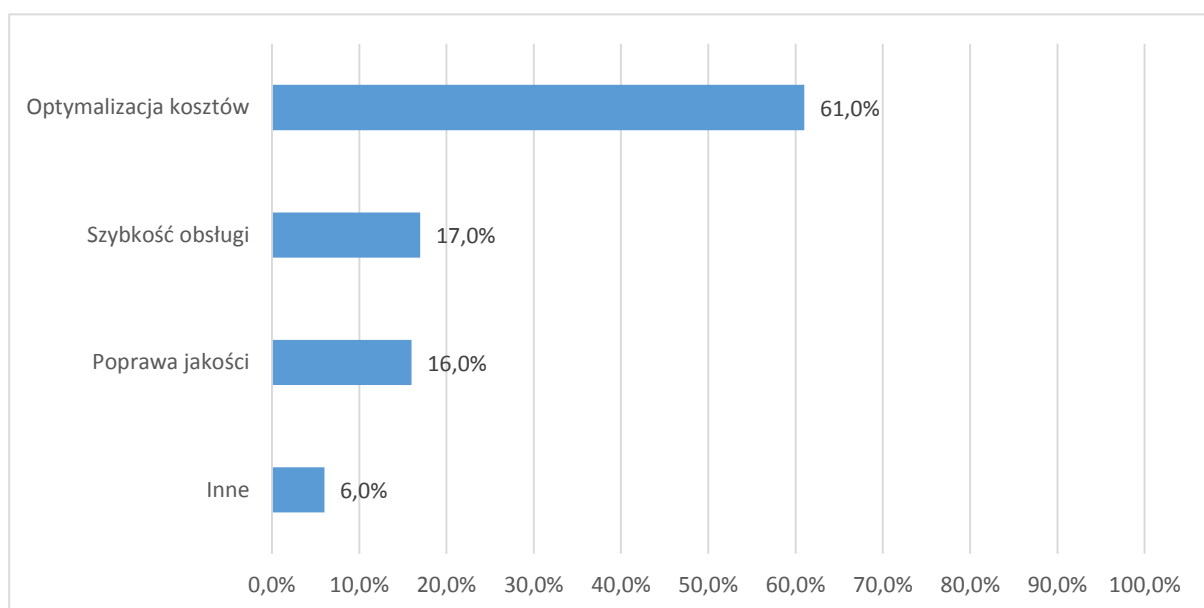


Figure 2. Objectives of IPA (intelligent process automation) implementation in the surveyed centers in Poland.

Source: Sektor Nowoczesnych Usług Biznesowych w Polsce (2024).

4. Challenges the sector may face in the near future.

According to McKinsey's Global Future of Work report, by 2030 process automation in Shared Service Centre organizations could contribute to a 30% reduction in routine jobs worldwide (Future of Work, 2025). Taking into account that the Polish modern business services sector is heavily involved in Robotic Process Automation (RPA) and Intelligent Processes Automation (IPA), the ABSL's forecast of an increase in employment may prove to be too optimistic. At the same time, representatives of the sector do not see an immediate threat in the form of job cuts. Admittedly, the sector has reported employment growth of 3.8% in

2023/2024 and is planning for further job growth in 2025, albeit at a lower level than in the previous year. The share of AI and GenAI technologies is already at a high level of sophistication, indicating a faster rate of adoption and deployment than expected in previous years. This situation forecasts a significant transformation and change in the nature of the activities of many organizations operating in the area of modern business services. This change will primarily involve a shift from outdated business models focused solely on achieving simple cost efficiencies to dynamic processes based on the use of artificial intelligence. The new approach will not only increase efficiency, but also enable processes of higher complexity. The impact of AI and GenAI is not just reduced to the role of yet another automation enabler. It has a much broader transformational context. There is no doubt that AI is contributing to changes in employment demand patterns, but more importantly, it will shape new skill set expectations for the sector's future workforce.

According to ABSL's 2024 report, 74.4% of surveyed organizations in the modern business services sector in Poland planned to implement a transformation strategy in the first quarter of 2025. The three most frequently indicated elements of this strategy are: automation, process standardization and the use of artificial intelligence (AI). Figure 3 shows all the tools and activities that companies plan to implement as part of the implementation of this transformation strategy.

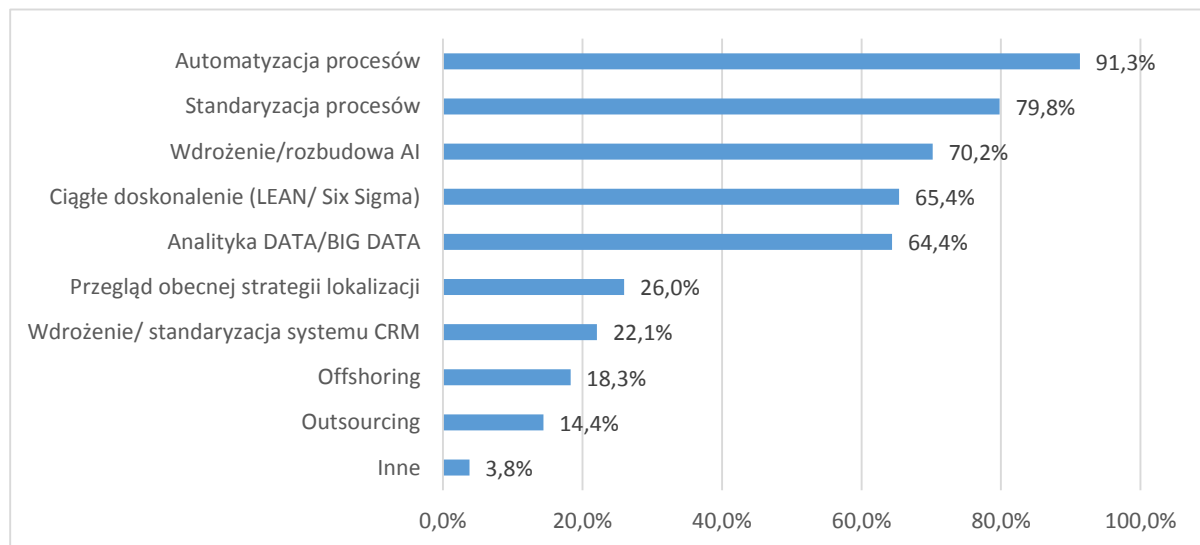


Figure 3. Key elements of the business process transformation strategy planned for 2025 in business services organizations in Poland.

Source: Sektor Nowoczesnych Usług Biznesowych w Polsce (2024).

It is worth to mention that one in five respondents points to location re-analysis as an important element of their business transformation strategy, and around one in six is considering offshoring or outsourcing. This indicates a new and growing threat to the Polish modern business services sector – in addition to the dynamic development of technology, there is a risk of relocation to countries offering lower operating costs, primarily in terms of wages and business operations. India is considered to be the greatest threat in the context of relocation

of services from Poland, indicated by as many as 24% of the surveyed companies. Among European locations competing with Poland, Romania, Spain, Portugal, Bulgaria and the Czech Republic are most frequently mentioned.

The ABSL association emphasizes that maintaining the global competitiveness of the Polish modern business services sector requires its transformation – from the implementation of simple, transactional processes to the provision of higher value-added services. It is crucial to implement more advanced functions and roles within business processes, as well as to invest in the development of employees' competencies, especially in the areas of expertise and expert skills.

Another factor pointing a threat to the relocation of services from Poland to other countries is the shortage of talent, i.e. qualified specialists for digital transformation roles. A similar problem is identified by Randstad in its Talent Trends report on the labor market in Poland in 2024. The report shows that the difficulty of recruiting employees with the right competencies and the growing shortage of key qualifications has reached record levels in Poland compared to other countries surveyed (Talent trends, 2024). The answer to this problem is to “pixelise the job” by redefining the current jobs and breaking them down into smaller parts – pixels – made up of tasks and skills. These chunks are then analyzed with the competences and tasks needed to achieve the organization's strategy and goals. The second element that has visibly gained in importance is the change in the attitude of companies towards different, more flexible forms of cooperation and employment of employees (from the traditional full-time position to the employment of temporary or contract workers). The percentage of companies that say they are interested in such forms of collaboration has increased from 40% in 2016 to 65% in 2024.

5. Summary

The modern business services sector is an important industry with a significant contribution to the development of the Polish economy in areas such as employment, contribution to national GDP, development of urban centers to increasing innovation in the Polish economy. Despite many unfavorable phenomena in the economic and political space, starting with the COVID-19 pandemic, disruption of global supply chains or the armed conflict in Ukraine, the industry shows a stable position and even forecasts further growth. The rapid development of modern technologies including, above all, artificial intelligence AI/GenAI is seen by the industry as an opportunity rather than a threat. New technologies are transforming the nature of the activities of modern business services organizations from being typically transactional to carrying out knowledge-intensive and more innovative tasks and processes that generate intellectual value. In this context, the challenge will be to find employees with the competencies of the future who can work with and handle new technologies.

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INNOVATION AND COMPETENCES OF EMPLOYEES IN THE CONDITIONS OF SUSTAINABLE DEVELOPMENT AS A NEW PERSPECTIVE IN HUMAN RESOURCES MANAGEMENT

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Purpose: The aim of the study is to present the significance and determinants of innovation in human resources management, with particular emphasis on the importance of competencies in striving for sustainable development of enterprises, which constitutes a new perspective in human resources management and in the functioning and development of modern enterprises.

Design/methodology/approach: In the theoretical part, the literature on the subject was analyzed. In order to answer the research questions, the diagnostic survey method was used (research technique: survey).

Results: The conducted research was based on defining the essence of human resources management in the context of sustainable development. The significance and conditions of innovation in this area were indicated, with particular emphasis on the significance of competences in the digital economy in striving for sustainable development. Key competencies were identified and the level of their acquisition in the small and medium-sized enterprises studied was assessed. It was assumed that the most important determinant of the innovativeness of enterprises are key competencies, which are shaped by actions taken in the area of human resources management in the conditions of sustainable development, which also has an impact on innovative activities in the personnel area.

Research limitations/implications: The results obtained during the empirical research are definitely survey-based and cannot be transferred to the entire population of small and medium-sized enterprises operating on the Polish market. It is planned to expand the research in the future to include a larger, more diverse research sample.

Practical implications: The research results and conclusions constitute implications for the development of competencies appropriately adapted to management challenges in the context of environmental changes. Key competencies constitute a condition for innovation in the personnel area in pursuit of sustainable development, which in turn determines the innovativeness of the company adapting to changes in the environment (sustainable development, digitalization).

Originality/value: The article shows the importance of competences and innovations in human resources management in striving for sustainable development of enterprises, which constitutes a new perspective on the functioning and development of modern enterprises, including SMEs.

Keywords: innovation, competences, human resources management, sustainable development.

Category of the paper: Research paper.

Introduction

Innovations in human resources management in the context of digitalization and sustainable development are an important issue in the context of a dynamically changing business and social environment. Implementing innovative solutions in human resources management is becoming increasingly important for companies that strive for a balance between achieving business goals and taking care of social, environmental and economic aspects.

Innovating in human resources management contributes to creating more effective, sustainable and competitive organizations that effectively cope with the challenges of the modern business world and society. At the same time, it allows companies to play an active role in promoting sustainable development and keeping up with changes in the digital economy.

Sustainable development of an enterprise means not only improving the financial and property situation of the entity, but also improving the living conditions and quality of employees and raising standards related to environmental protection. The ultimate goal is therefore to achieve a balance between the economic, social and environmental dimensions, which contributes to sustainable development on many levels (Misztal, 2019). The company's responsibility for the innovative activities undertaken, efficient use of resources, reduction of harmful emissions, improvement of working conditions and care for the external environment are key to achieving sustainable development and creating enterprise value.

The aim of this article is to determine the essence and conditions of innovation in human resources management in pursuit of sustainable development of enterprises, which constitutes a new perspective of functioning and development of modern enterprises. Based on the analysis of the literature on the subject, the main challenges related to introducing innovation in human resources management in a modern enterprise in the conditions of sustainable development and digital economy, where key employee competences are of great importance, were indicated.

The digital economy has a significant impact on the functioning of enterprises, because rapid technological progress is changing the environment of enterprises, forcing change in all areas of management, including primarily in human resources management. It is becoming necessary to use information and communication technologies in enterprises (digital intensity), as well as the broader development of the organizational capabilities of enterprises, including the competences of employees and management staff.

Competencies are a certain potential that is released in human behavior in the work environment, interactions with co-workers. Employee competencies determine the value of modern organizations, which is why the best employees are constantly sought and their competencies are sought to be shaped and developed. Competencies of employees and managers are the main element of the competencies of an organization. It is people - their knowledge, skills and commitment, as well as the ability to cooperate - that shape and develop enterprises, products and technologies, build the brand of the enterprise and its

products. This also applies to small and medium-sized enterprises and employee competences. Based on the results of empirical research, the importance of key competences was assessed and the level of acquisition of individual types of competences for the needs of SMEs in the conditions of the digital economy was assessed in the context of the challenges of human resources management and innovation in this area in the pursuit of sustainable development. The research period covered the years 2020-2022.

1. Literature review

1.1. Human Resource Management and Sustainable Development

The concept of sustainable development is analyzed both at the macro level, related to the progress of the world and civilization, and at the micro level, where it focuses on enterprises. In the macro perspective, sustainable development includes the goals set by the United Nations and policies in individual countries. In turn, the micro perspective focuses on enterprises that are still looking for their own definition of sustainable development and practical guidelines for its implementation. The concept of sustainable development is based on stakeholder theory, which assumes taking into account the expectations of groups or individuals who may affect the goals or activities of the organization. Although generating profit remains the key goal of the company, the concept of sustainable development takes into account the balance between economic, social and ecological goals. It is a process in which these three categories of goals are balanced, enabling sustainable development (Grzesik, 2023, p. 75). Sustainable development of a company can be understood as the process of meeting the needs of both direct and indirect stakeholders of the company, while maintaining the ability of the company to satisfy the needs of future stakeholders. Sustainable development of a company is also defined as achieving success in the present, while not compromising the needs of future generations. In practice, this means that the company strives for a balance between current goals and the long-term consequences of its actions (Misztal, 2019, p. 37).

Sustainable development of enterprises therefore includes comprehensive actions aimed at achieving their primary economic goal, while taking into account social and environmental aspects in accordance with ecological standards. According to these assumptions, "the financial goals of an enterprise must include social and ecological aspects as the main areas of sustainable development" (Trojanowski, 2015, p. 240). Sustainable development of an enterprise, also identified as green development of the economy, is a path of socio-economic development that more effectively implements the goals of sustainable development. An equally important element of this process is the introduction of effective organizational management. It allows for continuous monitoring and adaptation of the enterprise and its subsystems to changing external

conditions, which enables the enterprise to effectively manage resources and processes, in accordance with the principles of sustainable development. A sustainable approach also applies to the area of human resources (social subsystem) and human resource management.

In the literature, the human resource in an organization is usually defined by a key component, such as knowledge, abilities, skills, health, attitudes and motivations of employees. Within this resource, individual employees play a key role, deciding on the degree of commitment to the implementation of the tasks assigned to them (Ślusarczyk, 2018, p. 14). Human resource management in this context refers to the personal aspects of enterprise management and building positive relations between employees and the management of the organization. Its aim is to effectively use the abilities and knowledge of employees, while providing employees with appropriate benefits, both material and non-material, for their commitment.

Human resource management includes three main dimensions: functional, institutional and instrumental. In the functional dimension, it focuses on organizing tasks and activities into value-generating processes. In the institutional dimension, it refers to defining the roles and competences of entities responsible for making personnel decisions and the relationships between them. In the instrumental dimension, it focuses on selecting appropriate methods and techniques for solving problems related to personnel management (Ślusarczyk, 2018, p. 14). Innovations in HRM can therefore refer to the indicated dimensions, in which process and organizational innovations prevail.

Modern enterprises face a significant challenge – sustainable human resource management. The aim of this management is to facilitate the organization in achieving success through the effective use of employees and at the same time satisfying their needs. Modern human resource management systems are not only a tool for fulfilling duties, but also a source of skills enabling the organization to acquire and capitalize on new opportunities. Human resource management in a modern enterprise focuses on achieving economic and social goals through employee engagement and efficiency. In the context of increasingly frequent use of the latest information technologies in enterprise management, human capital is becoming a key area of investment. Long-term sustainable HR policy is necessary to achieve this goal, with particular emphasis on innovation in the personnel area.

Innovations provide companies with a number of benefits, such as the ability to better adapt to market changes or the ability to compete with other companies. However, undertaking innovative activities carries certain challenges. The risk and uncertainty associated with introducing new solutions may give rise to fears of unknown effects, especially in relation to human resource management and the probabilistic nature of the social subsystem. Despite this, companies should incur financial outlays on research and development, as well as continuously invest in innovation initiatives with particular emphasis on the area of human resources (Wysocki, Wesółowski, 2015, p. 35).

It should be emphasized that for small and medium-sized enterprises operating in conditions of dynamic changes, innovations are not only a tool for survival. They are also a key factor determining their development and future success in an increasingly competitive market, based on human potential.

1.2. Innovation in human resources management

The economy is constantly changing, which requires managers to respond to these changes and take advantage of emerging opportunities. In this context, innovation is a key factor that allows enterprises to adapt to the dynamically changing environment through a conscious search for new solutions, creativity in resource management and the ability to transform challenges into opportunities. Entrepreneurs, using innovative instruments, are able to better understand market expectations, adapt the enterprise to new trends and, as a result, compete more effectively.

Innovation in human resources management is a concept that includes ideas, policies, programs, practices or systems related to the personnel area, if they are innovative in the context of the organization adopting them (Ciekanowski, 2018, p. 156).

Enterprises are introducing innovations in human resource management in pursuit of sustainable development, where competencies are a key resource, capital. Sustainable development, corporate social responsibility, in addition to business orientation, increasingly concern HRM. There are connections between HRM strategies (and feedback) and the mission, vision and organizational culture oriented towards sustainable development. The importance of people in the organization as human capital (including competencies) for achieving results (including innovation) is particularly important here, they are characteristic of the philosophy and model of HRM/HRM in contrast to the earlier PM model (personnel management). (Oleksyn., Stańczyk, Bugaj, 2011, p. 212).

In innovation management, the instruments of managerial influence are focused on innovation competences, on shaping and popularizing innovative behaviors, on stimulating learning processes. In traditional innovation management, the influences are directly focused on the innovation process (Pomykalski, 2001). In the subjective approach, greater intensity of introducing innovations is achieved indirectly by earlier shaping of people's ability to introduce innovations, i.e. equipping them with innovation competences. In order to increase the effectiveness of innovation management, an egalitarian approach to innovation is required. According to this approach, this philosophy, innovation would be treated as a competence available to each member of each organization, as a universally occurring phenomenon. The effectiveness of innovation management based on the development of human capital can be measured by the degree of manifestation of innovative behaviors (Bal-Woźniak, 2020, p. 24). Therefore, the number of participants in the innovation process is increasing. Therefore, the next generation innovation models are distinguished, with particular emphasis on integrated models, network models, open innovation models, in which the number of participants in the

innovation process is increasing in pursuit of sustainable development. Innovation models as theoretical constructs constitute a schematic description of the ways of generating innovation in organizations, taking into account the flows of various types of knowledge (Bal-Woźniak, 2020, pp. 48-53).

In this study, it was assumed that innovation in HR can also be defined as the ability to implement innovations in the personnel area, aimed at improving processes such as recruitment and selection of employees, employee development, employee motivation and assessment. Innovations in this area allow for the creation of the potential of the organization, which are innovative employees introducing changes in an innovative enterprise in the context of changes in the environment, with particular emphasis on the concept of sustainable development.

In the context of human resources management, innovations include all solutions that are novel, creative and lead to changes in the current state of affairs. Organizational innovations, which dominate in HRM, mean the implementation of new methods, especially in the area of work organization in specific positions. They are often associated with process innovations, which involve introducing new ways of providing services. Understanding innovation in human resources management requires a flexible approach to traditional personnel functions and readiness to adapt to new trends (e.g. sustainable development) and changing needs of the organization. Innovative human resources management is becoming a key element in a dynamic business environment, where organizations try to adapt to contemporary challenges and achieve competitive advantage through a creative approach to human resources management (Sankowska, 2009, pp. 95-97).

Human resource management is therefore becoming extremely important in the context of creating an organizational culture that supports innovation and in the processes of recruiting, training and motivating employees. It should be emphasized that an innovative employee has not only great imagination and ingenuity, but also specific character traits and skills that play a key role in the innovation process (Nowakowska, 2023, p. 50).

An innovative employee is ready to accept and process new information, search for different solutions and take on new challenges. Implementing innovation requires teamwork, which is why an innovative employee should have communication skills, the ability to resolve conflicts and flexibility in working with others. Innovation also requires the courage to experiment, make decisions in conditions of uncertainty and accept greater risk. It should also be emphasized that an innovative employee should be well-versed in new technologies, processes and trends. Having specialist knowledge allows for the creation of innovative solutions. An innovative employee should be able to analyze data, which allows for making decisions based on knowledge (Nowakowska, 2023, p. 51).

Human resource management in innovative companies is crucial for identifying, developing and retaining innovative employees. Creating the right work environment that supports the development of innovation skills and promoting an open organizational culture can significantly contribute to the company's success in innovation in the conditions of sustainable development.

A particular challenge occurs in the case of organizations with deeply rooted traditions, based on strictly defined procedures and established habits. In such a case, human resources management requires radically innovative, creative and innovative actions. Responsible management should be focused on the effective use of employees' knowledge, abilities, skills and motivation to implement changes that generate progress and are characterized by signs of creativity (Ciekanowski, 2018, p. 158). In a business environment where striving to increase customer satisfaction is a priority, employee engagement also plays a significant role. Their active role in the implementation of tasks, initiative, flexibility of thinking and the ability to create changes and adapt to changes, have an impact not only on the internal processes of the organization. It is also important for creating the image of a modern, innovative organization (Janowska, 2010, p. 13).

The problem of using the potential of employees in increasing innovation became the subject of the Polish-Norwegian research project "InnoGend", managed by the Jagiellonian University in cooperation with the University of Warsaw and the Ostfold University in Norway in 2013. The research of the Jagiellonian University team was focused on the determinants of the ability of women and men to innovate. The aim of the study was to determine the importance of personal characteristics, abilities, skills, roles and attitudes in the innovation process in the context of differences resulting from a given gender. The impact of diversity on innovation was therefore studied, assuming that employee diversity creates a broader basis for search and thus affects employee creativity and openness to new ideas. This is also a challenge for human resources management in the context of increasing innovation. Research results indicate that the participation of women and men in the innovation process is different, although it has common elements. Women bring to it higher levels of trust, focus on people, risk appetite and decision-making ability. Men, compared to women, bring significantly higher levels of focus on competencies, tasks and an unconventional way of thinking and acting. In addition, the research results indicated the work environment (atmosphere, relationships, attitudes, incentives and rewards) as the most important determinant of the innovation process. According to women and men, their innovation activities are also supported by: training, flexible working hours, financial incentives and promotion at work. Due to the importance of the involvement of both sexes in the innovation process and the importance of innovation for economic growth, it has also been shown that a specific set of institutional instruments should be used to engage women and men in creating innovations (Zachorowska-Mazurkiewicz, Sierotowicz, 2026).

To sum up, it should be stated that sustainable development of enterprises is currently an important area of interest for researchers, especially in the context of taking actions for sustainable development with particular emphasis on innovation in HRM in small and medium-sized enterprises, where digital competences are becoming increasingly important as key competences.

2. Research methodology and results

The aim of the study was to diagnose the importance of key competencies and to determine the level of acquisition of selected types of competencies in the practice of SME management in Poland in 2020-2022 in the context of the challenges of the digital economy. This study was conducted among a purposefully selected research sample, covering 100 small and medium-sized enterprises operating in Poland. Empirical research was carried out using the CATI method with owners or managers of the surveyed enterprises (50 small companies and 50 medium-sized companies). Responses were obtained from 100 respondents. It should be emphasized that the results obtained during the empirical research are definitely of a survey nature and cannot be transferred to the entire population of small and medium-sized enterprises operating on the Polish market. However, they characterize and provide an approximate assessment of the issue of competences in managing small and medium-sized enterprises.

2.1. The importance of key competences in small and medium-sized enterprises in the digital economy

Employee competencies are the main element of the organization's competencies. Among the competencies of the organization and employees, key competencies play a special role. Key competencies are common to all employees and are the most important in achieving the goals of a modern organization in pursuit of sustainable development in the digital economy. The results of the conducted research indicate that the key competencies in the surveyed enterprises in relation to the requirements of the digital economy (Fig. 1) include: resistance to stress and flexibility (61% of indications), decision-making (53% of indications), creativity (52% of indications).

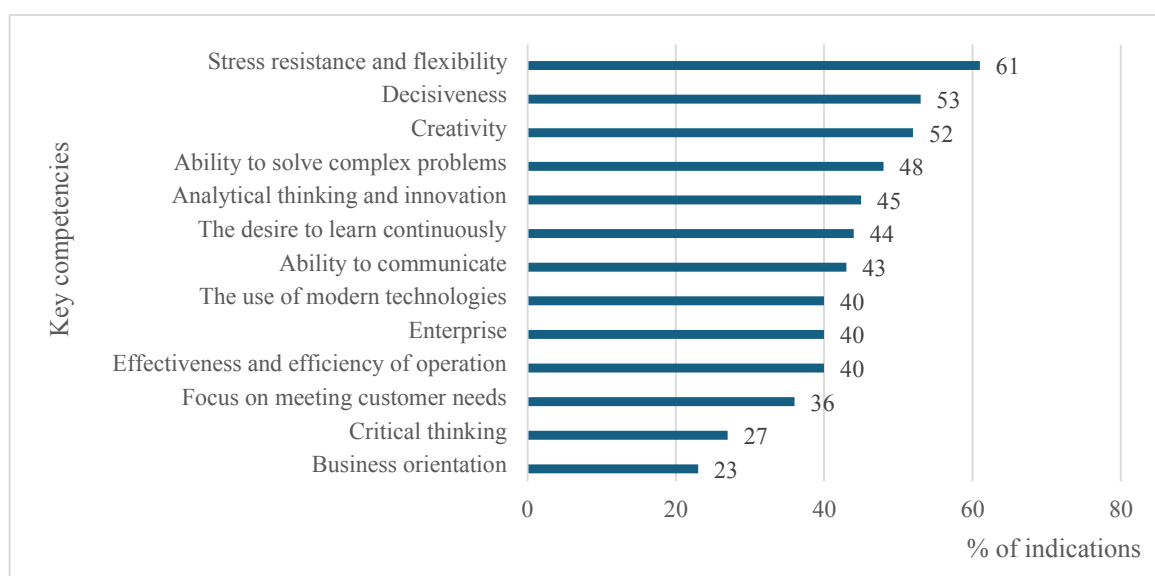


Figure 1. Key competencies of employees in the surveyed enterprises in 2020-2022 (in total).

Source: own study based on data from the empirical study of the Institute of Management 2023.

In light of the research results, it can be stated that in the conditions of digitalization, the ideal employee in small and medium-sized enterprises is one who is primarily resistant to stress, is flexible, i.e. oriented to change, can find pleasure in acquiring new skills and derives satisfaction from continuous learning. Stress resistance and flexibility help overcome even the greatest crisis and respond appropriately to new challenges, which in the long term allows to maintain the stability of the organization and its resistance to external factors.

In addition, the challenges of the digital economy require decision-making in SMEs. A modern enterprise operates and develops based on many different elements and processes. The large number of variables and connections means that the ability to make decisions based on acquired information and knowledge is crucial. Employees who are able to draw the right conclusions will be able to make effective decisions that improve processes and introduce innovative solutions. In the context of decision-making, respondents also largely indicated the importance of the ability to solve complex problems (48% of indications) and analytical thinking and innovation (45% of indications).

Flexibility and decision-making in SMEs in the face of digitalization require creativity. This is, to a large extent, a desired and sought-after employee competence by Polish entrepreneurs, inextricably linked to demonstrating initiative. Employees who can approach the tasks they are given in a creative way strengthen the development potential of the organization they work for. They can contribute to strengthening its position on the market through innovative solutions.

The research results (a large percentage of responses, primarily 40% and more responses) allow us to state that respondents (managers and co-owners) are aware of the importance of many competencies, especially those that affect the innovativeness and competitiveness of SMEs in the context of new technologies, with particular emphasis on digitalization. For respondents, the least important competency is business orientation (23% of responses), which concerns competencies related to a specific area of the company's operations. This probably results from the awareness of managers that business orientation, even in SMEs, in today's conditions and changing environment, is not enough. Competencies focused on meeting customer needs, related to the orientation on social and environmental (ecological) aspects in the context of sustainable development, social responsibility and digitization, are also necessary and important. This therefore also applies to small and medium-sized entities and their changes in the context of emerging mega trends, which is reflected in employee competencies.

In summary, the indicated competencies of employees in the surveyed SMEs confirm the awareness of respondents regarding the importance of competencies, especially those key to the development and competitiveness of such enterprises in the digital economy, where knowledge and innovation are the basis for development. This primarily concerns key competencies such as: resistance to stress, flexibility, decision-making, creativity. An important

role, in addition to key competencies, is also played by competencies such as: corporate, job-related, social, technical, as well as their level in a given organization.

2.2. Assessment of the level of competence in small and medium-sized enterprises

Changes in the field of people management (forced by technical, technological, organizational, economic and social progress) concern the perception of a human being in management as a creator, innovator, creative executor of the enterprise's strategy.

Managers and employees of a company constitute its social subsystem, which accumulates the potential of innovation and creativity, which is based on their knowledge, will, desire and possibilities. The tasks of owners, managers of a company within the framework of human resources management include, first of all, hiring the right people, using their potential and their creative development, as well as shaping motivation. Sustainable human resources management means orienting human work and people towards the enterprise's goals in the long term, i.e. focusing on the future, on the enterprise's development in the context of building human potential that ensures the enterprise's success – its innovativeness and competitiveness (Wachowiak, Winch, 2014, p. 113).

Employee competencies are determined not only by the characteristics of the staff, but are also shaped by the innovativeness of human resources management. Unleashing creativity and innovation in employees is conditioned by various reasons. The main ones are assumed to be building employee competencies, creating organizational flexibility, unleashing a sense of agency and ensuring personal development.

The way to group competencies at the level of position, department, division and enterprise is to combine them into three groups:

- social (interpersonal) competencies - a group of competencies related to the quality of functioning and the quality of contacts with other people,
- professional (functional, position) competencies - a group of competencies related to activities within the scope of the performed profession and/or function,
- business (corporate) competencies - a group of competencies related to the specific area of activity of a given person and the functioning of the enterprise.

Moreover, in the digital economy, technical (digital) competences, related to the effective use of information society technologies, are of particular importance. The following levels of assessment were adopted to assess the degree of acquisition of the above-mentioned competences (Walkowiak, 2007, p. 25):

- competence acquired to a perfect degree, the person creatively uses knowledge, skills and attitude appropriate to a given scope of activities,
- competence acquired to a very good degree, enabling very good performance of tasks from a given scope and sharing one's own experiences with others,

- competence acquired to a good degree indicates acquisition of competence to a degree allowing independent, practical use of it,
- competence acquired to a basic level is used irregularly; the person requires active support,
- lack of acquired competences enabling effective performance of tasks, lack of behaviour indicating the use of a given competence.

The obtained research results allowed for the assessment of the level of acquisition of competencies by type, i.e. company, job, social and technical competencies in the surveyed SMEs. In the years 2020-2022, competencies were assessed in SMEs as acquired to a very good and good degree. In the surveyed enterprises, the largest number of respondents indicated the following level of acquisition of competencies by type (Fig. 2), namely:

- company competencies – good level of acquisition – 44% of responses,
- job competencies – very good level of acquisition – 41% of responses,
- social competencies – very good level of acquisition – 42% of responses,
- technical (digital) competencies – very good level of acquisition – 44% of responses.

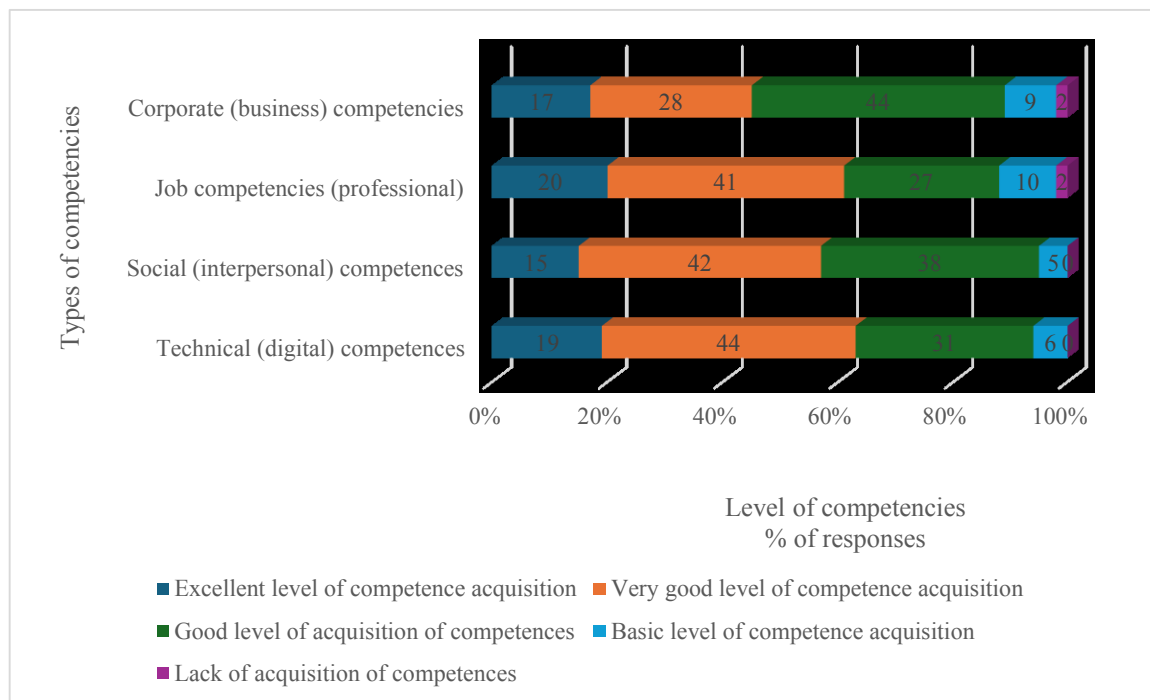


Figure 2. Assessment of the level of competences in the surveyed enterprises in 2020-2022 in total.

Source: own study based on data from the empirical study of the Institute of Management 2023.

In summary, the assessment of the level of competences in the surveyed SMEs in 2020-2022 is very positive. Respondents' answers indicate that competences are acquired to a very good, good and excellent degree, which may indicate high staff potential, i.e. the quality of human resources that are capable of achieving goals (including innovative ones) in small and medium-sized enterprises in the digital economy. This may result from the importance of employee competences in the development and success of small and medium-sized enterprises

and their connection with the creation and implementation of innovations in human resources management, which innovations are also aimed at increasing employee competences.

3. Discussion and conclusions

The subject of sustainable development is an enterprise that adopts the principles of fulfilling social, ecological and economic criteria in strategic plans and operational management. This therefore primarily concerns the implementation of the personnel strategy and human resources management in pursuit of sustainable development and innovation (Wachowiak, Winch, 2014, p. 33). The concept of HRM is evolving towards human capital management (and more broadly: intellectual capital management). It has been assumed that human capital is all resources (knowledge, experience, skills, abilities, attitudes, values) embodied in people, which are a source of future profits for both the employee (owner of human capital) and the enterprise using this capital. The components of human capital, i.e. knowledge, skills, recognized values, and formed attitudes, also indicate the structure of employee competences that translate into its innovativeness, i.e. (Bal-Woźniak, 2020, p. 23):

- the employee is able to perceive innovative situations (innovations are valuable),
- the employee is ready to engage in the creation of new ideas and technologies (positive attitude towards the new),
- the employee creates new solutions (has specific knowledge and has the skills to use it),
- the employee is able to implement new solutions (has a sense of their own agency, introducing changes).

In connection with the above, innovation falls within the scope of human capital. This also applies to small and medium-sized enterprises, which dominate the economy. Therefore, empirical research was undertaken to determine the conditions for innovation in human resource management in pursuit of sustainable development of enterprises in the context of key competencies of SME employees, which constitutes a new perspective on the functioning and development of modern enterprises, including small and medium-sized ones.

As a result of the empirical research conducted in 2023, synthetic conclusions were formulated on the competences in small and medium-sized enterprises in the years 2020-2022. Namely:

- key competences, such as: resistance to stress and flexibility, decision-making and creativity in SMEs also have an impact on the success of the organization in the context of the digital economy and the pursuit of sustainable development,
- the level of acquisition of corporate, job-related, social and digital competences was assessed positively by most respondents, i.e. at a very good and good level.

It should be emphasized that the results obtained during the empirical research are definitely of a survey nature and cannot be transferred to the entire population of small and medium-sized enterprises operating on the Polish market. However, they characterize and provide a certain view of the issue of competences in managing small and medium-sized enterprises.

It should be emphasized that in the creation and development of organizations, the so-called entrepreneurial competences are becoming increasingly important, including personal characteristics such as: personality, motivation, self-efficacy, knowledge and cognitive mechanisms that determine effectiveness in establishing and developing business ventures. This applies to small and medium-sized enterprises, employees and managers. In entrepreneurial competences, the basis is entrepreneurial knowledge regarding the ability to find and compare information leading to the identification of opportunities in the environment and sensitivity to these opportunities. Entrepreneurial competences are dynamic in nature, they are shaped in connection with performing tasks, therefore they can only partially be innate. The learning process in the context of internal and external stimuli, in the context of a dynamically changing environment, has the greatest impact on shaping this type of competence. SME competences (including company, job, social, digital competences) should therefore evolve towards entrepreneurial competences. This results from the importance of competences as a source of competitiveness, innovation, building the image of a responsible enterprise, which strengthen the development potential of enterprises in the context of changes in the environment.

The idea of sustainable development introduces a number of challenges to organizations, including SMEs, related to the need to change and adapt HR policies to the concept of sustainable development by introducing innovations in this area. These are the following challenges (Grzesik, 2023, p. 76):

- diversity,
- organizational justice,
- employee development,
- progress orientation,
- work-life balance.

The above-mentioned challenges and at the same time attributes of a sustainable enterprise indicate that sustainable development is not only focused on current results, but also on the long-term well-being of the organization, employees and society. Meeting these challenges requires implementing process and organizational innovations in the personnel area, especially in relation to employee selection, development, motivation and assessment. Which has an impact on increasing employee competences and, as a result, on the organization's innovativeness and innovations implemented in human resources management.

Corporate, job, social and technical competencies together constitute the scope of the enterprise's competency potential. Their individual dimension will depend on the management level and the level of competence acquisition. At the lowest level of the management hierarchy,

job competencies are the most important. Their scope decreases accordingly at the remaining management levels. Technical and social competences are important at every level, while the greatest range of business (corporate) competences is required of managers at the highest management level. The boundaries of competence ranges are not sharp, as they change depending on the size of enterprises and teams directly or indirectly supervised and on task situations, as well as human resources management. In light of the above considerations, it seems justified to continue research on competences and their impact on the innovativeness of enterprises according to the size of enterprises, type of activity and changes in the environment.

Effective management of a modern enterprise is an extremely complex process, which uses not only technological and material factors, but above all the intellectual potential of employees. Therefore, every enterprise striving to develop and conquer new markets should pursue a balanced HR policy. The main goals of this policy include employment, remuneration, professional development, training, motivation and work evaluation. All these aspects make up a comprehensive, innovative approach to human resources management in the context of sustainable development and the digital economy. In the modern approach to human resources management, emphasis is placed on key competences, mainly innovative skills, which are a key element enabling individuals and organizations to introduce innovative and more effective solutions in the pursuit of sustainable development. Such skills cover various areas, such as creativity, critical thinking, analytical skills, interpersonal skills, as well as technical and numerical skills. Innovative competences, in addition to skills, are also personality traits and attitudes that support the innovation process. These include openness to new ideas, initiative, the ability to take risks, self-discipline, flexibility and the ability to cope with uncertainty and contradictions. Employees with innovative competences are able to accelerate the innovation process, including the pursuit of sustainable development, enrich ideas and develop and implement new products. Innovative competences enable individuals and organizations to overcome barriers, seize opportunities and create conditions conducive to innovation. Importantly, modern innovative organizations care about employees with both specific technical skills and character traits that support a creative approach to challenges. These competencies are necessary to effectively cope with the dynamic business environment and to maintain market competitiveness in the context of sustainable development (Nowakowska, 2023, pp. 53-54). Enterprises focused on sustainable development are more willing to invest in innovations related to environmental protection, ethics and corporate social responsibility, including HRM. This approach can contribute to the creation of innovative solutions also in SMEs, which will not only improve financial results, but also bring social and environmental benefits.

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TOURISM OFFER MANAGEMENT INFLUENCE ON VISITORS' PERCEPTION IN MAŁOPOLSKA

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Purpose: The purpose of this paper is to assess how the quality and structure of tourism management in the Małopolska region influence its evaluation by domestic and international tourists. The research aims to identify key elements of the tourism offer that shape destination perception and satisfaction, as well as to propose a method for objective measurement of destination image using synthetic indicators such as WAED (Element Attractiveness Indicator) and ZWAD (Integrated Destination Attractiveness Index).

Design/methodology/approach: The study is based on a large-scale quantitative survey conducted among 5,278 domestic and international tourists visiting the Małopolska region in 2024. Data were collected through direct interviews using electronic questionnaires. The research utilized Likert-scale evaluations of 30 elements of the tourism offer, enabling the calculation of WAED and the aggregated ZWAD.

Findings: The research revealed a generally high level of satisfaction among both domestic and international tourists regarding the tourism offer in Małopolska. The highest-rated elements included tourist information, gastronomy, and hospitality. The ZWAD index reached 4.39 overall, indicating a very positive perception of the region. Differences between domestic and international tourists were minor, with both groups consistently rating the destination favorably.

Originality/value: This study introduces a structured, indicator-based method (WAED and ZWAD) for assessing destination attractiveness from the tourist's perspective. It provides a unique empirical insight into the perception of regional tourism management in post-pandemic conditions and supports decision-makers in identifying areas for improvement and strategic planning.

Keywords: destination attractiveness, tourist satisfaction, Małopolska region, tourism offer evaluation, integrated tourism indicators.

Category of the paper: Research paper.

1. Introduction

Among the many types of tourism products, ORT (area of tourist reception = destination) is mentioned as a type of tourism product. Such a product is synergistic, i.e. that the interaction of the individual components of a place is more effective than the sum of their separate actions - so cooperation and care for the place is extremely important. It contributes to the creation of different types of tourism space.

The authors present in this article a method of assessing the level of management of a destination from the point of view of its users (tourists), which helps, on the one hand, to solve the problem of objectivising the image of a travel destination and, on the other hand, allows destination managers to take corrective action in selected areas - elements of the region's offer. Creating a true image of a destination is important for both stakeholders.

2. Research methodology

2.1. Research subject

The subjects of the research were domestic tourists (4,564 in number) and foreign tourists (711 in number) visiting Małopolska in the year 2024.

Considering the specificity of the (post-pandemic) year 2024 (as in previous years), a research sample of 5500-5000 questionnaires was used. The actual number of questionnaires analysed in 2024 was 5278 (Table 1 and 2). With a population of $N = 13$ million and a fraction estimate of $f = 0.5$, this implies an error of 1.5% with a confidence level of 95%.

Table 1.

Structure of the 2024 sample - percentage structure and in real numbers

Specification	%	Specification	N
Country	91,6%	Country	4564
Abroad	8,3%	Abroad	711
No data available	0,1%	No data available	3
Total	100,0%	Total	5278

Source: own study.

Table 2.

Age - percentage structure

Age	2024
up to 19	5,6%
20-29	30,6%
30-44	39,6%
45-60	18,7%
over 60	5,5%
Final total	100,0%

Source: own study.

The system adopted in the study for collecting data characterising the opinion of tourists staying in Małopolska was based on the method of direct interviews using tablets, with the help of which questionnaires were filled in electronically. It was assumed that a minimum of 5000 questionnaires would be obtained. This volume of survey data ensures an estimation error of no more than 1.5%, at a confidence level of 95%, for the current size of tourist traffic.

The survey covered visitors to Małopolska, defined in the UNWTO statistical recommendations as tourists (using at least one overnight stay) and one-day visitors who came for the following purposes: cognitive, leisure, professional, religious, family, health and other.

Survey time: The surveys were conducted between mid-June and the end of September 2024 according to the accepted distribution of sampling sites during each month. Nearly 5300 questionnaires were taken in 2024, but after initial verification of the correctness and completeness of the collected data, 5278 questionnaires were submitted to the database. The small number of rejected questionnaires testifies positively to the work of the interviewers.

2.2. Research area

The study area was Małopolska voivodeship (Table 3).

Table 3.

A list of the locations of the sampling sites and the number of questionnaires collected at each site and facility

No.	Location	N	%
1.	Zakopane – Krupówki/entry to Gubałówka	399	7,56%
2.	Chochółów – thermal baths/entry to Chochółowska Valley	355	6,73%
3.	Białka Tatrzańska – geothermal pools	354	6,71%
4.	Zawoja – entry to trails/Babiogórski National Park	340	6,44%
5.	Nowy Targ – entrance to trails e.g. Kowaniec - Turbacz and Gorce trails	330	6,25%
6.	Rabka-Zdrój – Pump Room/spa park/hiking trails	321	6,08%
7.	Kraków – Main Market Square	298	5,65%
8.	Kraków – Balice Airport	296	5,61%
9.	Zakopane – by the route and PKL cableway to Kasprowy Wierch/by the route to Morskie Oko (e.g. at the car park)	281	5,32%
10.	Wieliczka – Salt Mine	261	4,95%
11.	Gródek nad Dunajcem – Lake Rożnowskie	254	4,81%
12.	Niedzica/Czorsztyn – castle/barrage	248	4,70%
13.	Tarnów - town or Ciężkowice – Skamieniałe Miasto (Petrified City)	242	4,59%
14.	Ojców - entrance to Ojców National Park / town (optionally castle in Pieskowa Skała) /Kraków Dolinki Landscape Park	224	4,24%
15.	Krynica-Zdrój – town/ Pump room/ Ski station – by the viewing tower	200	3,79%
16.	Szczawnica – town/ Pump room/ cable car to Palenica/ end of rafting trip	190	3,60%
17.	Inwałd Park	186	3,52%
18.	Zator – Energylandia/parking lot at McDonald's/Zatorland	171	3,24%
19.	Olkusz – Błędowska Desert	170	3,22%
20.	Oświęcim – Auschwitz-Birkenau Museum	158	2,99%
	Total	5278	100,0%

Source: own study.

In total research were done in 20 locations. Locations were chosen based on their attractiveness and popularity. The choice of the location guaranteed differentiated and numerous research group.

2.3. A problem in the literature

In Małopolska such research (Borkowski, 2000) has been conducted since 2003 by the Intercollegiate Team of Experts of the Małopolska Tourist Organisation, consisting of: Krzysztof Borkowski, Tadeusz Grabiński, Renata Seweryn, Bożena Alejziak, Ewa Grabińska, Leszek Mazanek.

The similar research was conducted among 463 foreign tourists visiting Poland in 2014-2015 by Ghose and Johann. Their article explores how specific tour-package components and destination features influence tourist satisfaction and recommendations. Ghose and Johann show that well-organized tours (itinerary attractiveness, trip organization, guide service) and destination attributes (cultural attractions, monuments, safety) significantly boost visitor satisfaction and the likelihood of recommending the destination (Ghose, Johann, 2019).

This kind of research are also being done in other countries than Poland. For example, Johann and Anastassova analyzed how Polish package-holiday travelers perceive the quality of Bulgarian tourism offerings and how this relates to their satisfaction. Based on data from 1212 Polish tourists (2010-2013) in 14 seaside resorts, the study evaluates hotel attributes and finds Bulgarian hotels offer a competitive price–quality value that meets Polish tourists' expectations, contributing to overall trip satisfaction (Johann, Anastassova, 2014)

Using a survey (2012-2013) with 14 satisfaction indicators, Della Corte, Sciarrelli, Cascella, and Del Gaudio identified how destination attributes and services affect overall satisfaction and loyalty. Tourists in Naples were found not completely satisfied, revealing weaknesses in the tourism offer and the need for improved destination management (Della Corte et al., 2015).

Gargano and Grasso investigated tourist satisfaction and loyalty in a network of heritage villages in Sicily. Using an ordered logit model, they found visitor characteristics (e.g. age, country of origin) and services used significantly affect overall satisfaction. Moreover, satisfaction with specific aspects: local cuisine, trip price, and historical scenery has the strongest influence on tourists' intention to return (Gargano, Grasso, 2016).

An interesting finding were presented by Jimber del Río, Orgaz Agüera, Moral Cuadra and Cañero Morales, Focusing in their study on a cross-border tourism region of Dominican Republic and Haiti border. This study uses structural equation modelling to link tourists' attitudes, perceived value, satisfaction, and loyalty. Examining visitors on the Dominican Republic–Haiti border, the authors demonstrated that a positive attitude toward the border destination and high perceived value lead to greater satisfaction, which in turn fosters stronger loyalty represented through tourists' revisit intentions (Jimber del Río et al., 2017).

2.4. Research questions

Do the assessments of the 21 elements influencing the quality and management of tourism in Małopolska converge or differ in the opinions of the domestic and foreign tourist populations visiting the region? What is the reason for the differences in assessment by domestic and foreign tourists?

2.5. Research techniques

Visitors evaluating the tourism offer of Małopolska in 2024 used a five-point rating scale. Respondents rated individual elements of the destination as an area tourist product on a rank scale (on a Likert scale) from 1 to 5, where 1 meant status - 'very bad', 2 - 'bad', 3 - 'sufficient', 4 - 'good' and 5 - 'very good'. Using this scale, the subjective feeling of attractiveness of a destination in the opinion of tourists visiting Małopolska was measured, subject to further analysis. 'Using the Likert scale allows researchers to detect even relatively subtle differences in the attitudes surveyed. The advantage of this scale over simple scales is also evident in the fact that the individual items on the scale are not able to significantly influence the final result of the measurement. The items are meant to balance each other, given the constructed scale, whereas the particular properties of a simple scale can have a major impact on the conclusions drawn from the research' (Tarka, 2015, p. 287). The 30 selected components of the province's tourism product were assessed, obtaining a score for each element which was labelled 'WAED'- Destination Element Attractiveness Index. The results of the survey are presented in tabular statements with a division between domestic and international visitors introduced. The sum of the 'WAED' - Destination Element Attractiveness Indicators gives a complete indicator marked in the article as 'ZWAD' - Integrated Destination Attractiveness Index allowing to synthesise in an objectified way the image of a destination taken home by visitors. With a sample of more than 5000 respondents, borderline values of (minimum) 1.0 as well as (maximum) 5.0 are practically unattainable, so a score as close as 4.0-4.5 should already be considered very favourable for the managers of the analysed area. When interpreting the tables, it should be noted that a value of 3.0 is the inflection point of the scale and all scores above 3.0 are positive.

Given the specificity of the (post-pandemic) year 2024 (as in previous years), a survey sample of 5500-5000 surveys was used.

3. Results

The results of the study are presented in the form of graphs.

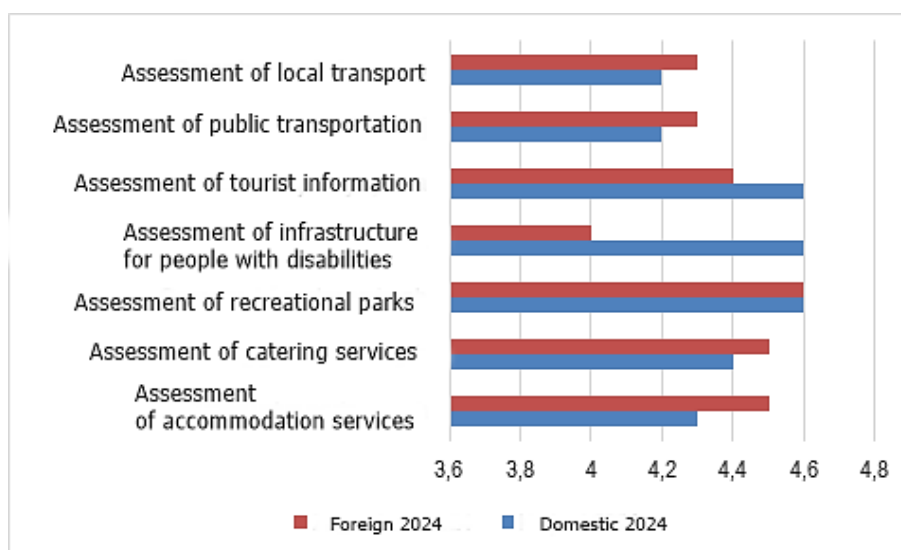


Figure 1. Opinions on tourism infrastructure in Lesser Poland voivodship.

Source: own elaboration based on survey.

The research shows that both domestic and foreign tourists rate the tourist infrastructure of Małopolska highly - with foreign tourists being slightly more enthusiastic. The regional catering facilities and the availability of tourist information received the highest marks, while the infrastructure for people with disabilities needs to be improved. Domestic tourists seem to have slightly lower expectations of local standards, but are generally positive about transport, public transport and recreational parks.

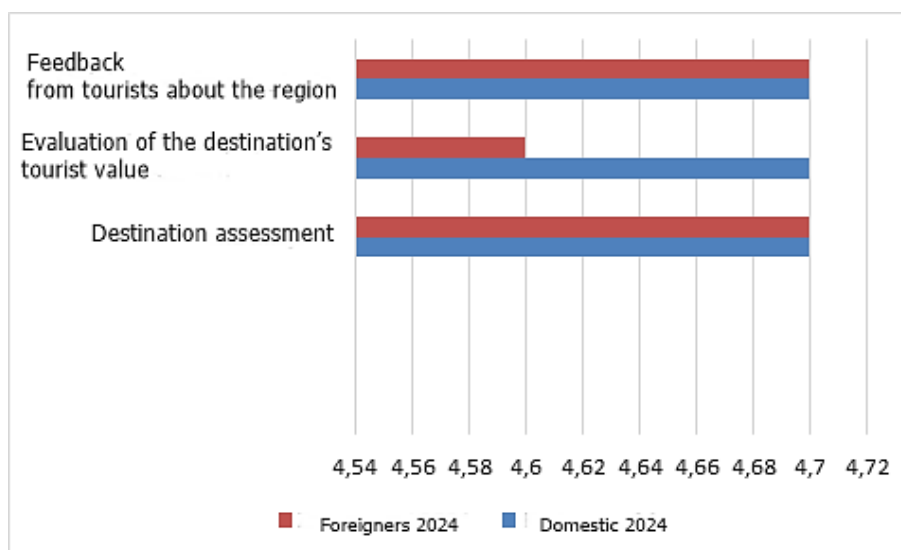


Figure 2. Tourists' opinions about the region.

Source: own elaboration based on survey.

The chart shows that both domestic and foreign tourists rate the region and its tourist attractions quite highly. All categories analysed scored above 4.5 on a five-point scale, indicating high satisfaction among respondents. Domestic tourists show slightly higher ratings (between 4.6 and 4.7), especially when it comes to tourist values and their overall opinion of the region. Foreign tourists perceive the region very similarly, although their ratings in some aspects (e.g. evaluation of a specific place) are marginally lower. However, the differences are not significant, which indicates a fairly consistent, positive impression of Małopolska on visitors from Poland and other countries.

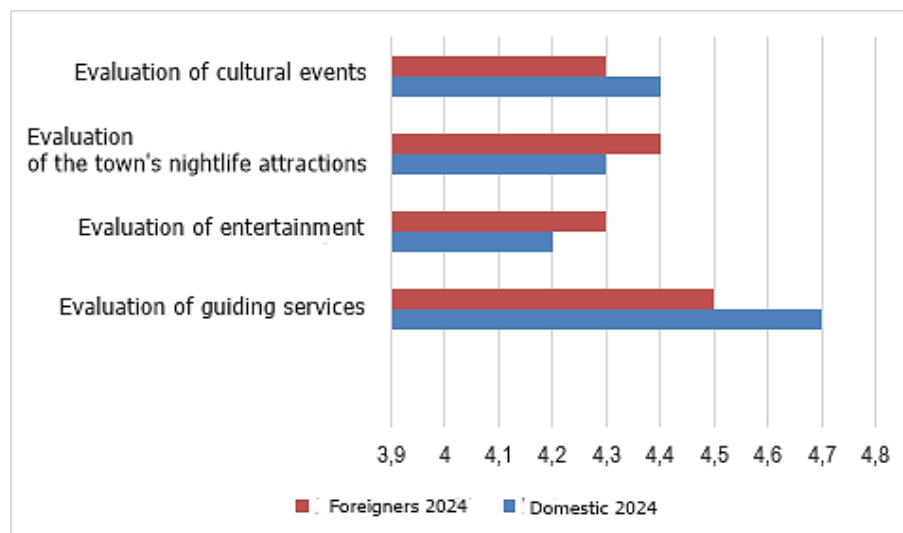


Figure 3. Tourists' opinions about services in Lesser Poland voivodship.

Source: own elaboration based on survey.

The chart shows that in 2024 both domestic and foreign tourists rate services in Małopolska highly. Cultural events and guide services received the best marks, with little difference between the groups. In the case of nightlife attractions, foreign tourists gave higher marks. All categories were rated good or very good, indicating the high quality of services in the region.

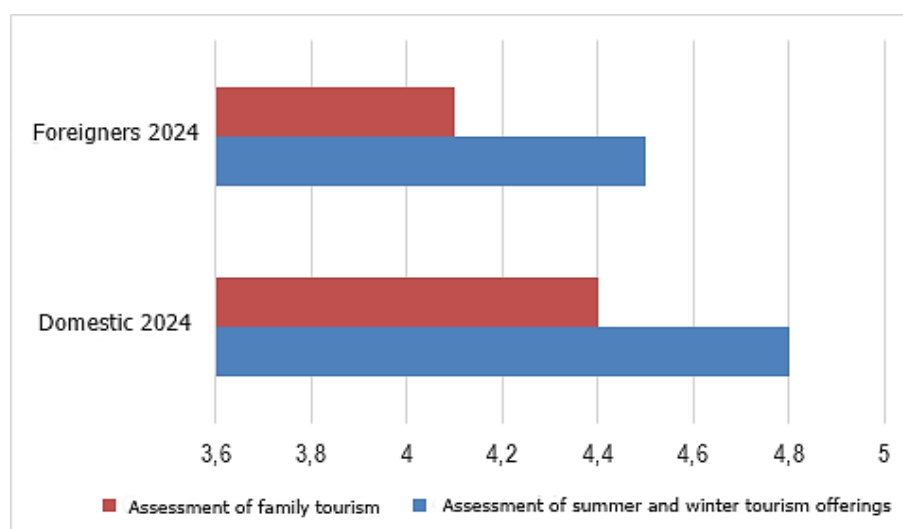


Figure 4. Tourists' opinions on forms of tourism in the Małopolskie Voivodeship.

Source: own elaboration based on survey.

The chart presented shows that domestic tourists rate both the family tourism offer and the summer and winter tourism offer in the Lesser Poland Voivodeship slightly higher. This may reflect their greater familiarity with local attractions and infrastructures adapted to the needs of families. Foreign tourists also rate all forms of tourism quite highly, paying particular attention to the picturesque landscapes and cultural richness of the region. However, the differences between the ratings are not significant, which confirms that Małopolska is able to attract diverse audiences and meet their expectations all year round.

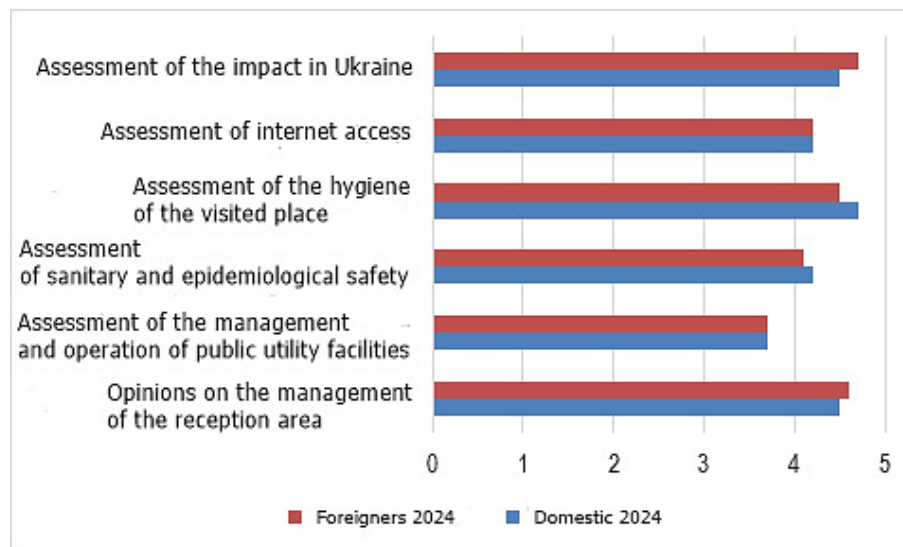


Figure 5. Tourists' opinions on the management of the reception site.

Source: own elaboration based on survey.

As the chart shows, both domestic and international tourists are satisfied with the with the management of the reception venue, especially in terms of internet access, sanitary safety and hygiene maintenance. Although guests note some impact of the geopolitical situation (war in Ukraine) on the operation of the venue, this does not significantly affect their overall rating. Internet access is rated at a satisfactory level and the high standard of hygiene maintenance is met with positive feedback, with domestic tourists giving slightly higher marks here. Sanitary and epidemiological procedures are also recognised by both groups, and the overall organisation and registration process are rated very well. In summary, despite the noticeable influence of external factors, the management of the reception site is held in high regard (Table 6).

Table 6.

Overall opinion Integrated Destination Attractiveness Index

Małopolska 2024	ZWAD Integrated Destination Attractiveness Index
Total – visitors	4,39
Domestic visitors	4,41
Foreign visitors	4,37

Source: own elaboration based on survey.

The overall opinions of the groups of the respondents, both domestic (4,41) and foreign (4,37) visitors are high. The total ZWAD Integrated Destination Attractiveness Index of visitors is 4,39.

4. Discussion

4.1. Opinions on the tourist infrastructure of Małopolska

4.1.1. Evaluation of accommodation services

Accommodation services that condition tourists' stay in the region are invariably a strong point of the tourist offer in Małopolska. In 2024, accommodation facilities were rated by domestic tourists at 4.29. The opinion of foreign tourists on this segment of services was even more positive than that of domestic tourists, as shown by the rating of 4.52. It should be noted that the facilities are very diverse in terms of type and category - from five-star hotels to agrotourism facilities. Thus, the opinion expressed in the assessment about the accommodation base, including its availability and range of services, deserves recognition and demonstrates the full acceptance of this offer by tourists.

4.1.2. Evaluation of catering services

Catering establishments and services are high on the list of the main tourist attractions of visited places and destinations. The catering offer in 2024 was appreciated by domestic visitors, who gave a rating of 4.42, and it was another consecutive year with such a high rating. Catering services were even more highly appreciated by foreign guests, reflected in a rating of 4.53. In both groups surveyed, these ratings are higher than the six-year average. It is worth noting that both groups of visitors expressed approval of the region's catering offer. This confirms that gastronomy is a very strong point in the tourist offer of Małopolska. Meeting the needs of guests, who are increasingly diverse in terms of their requirements and financial capabilities, is a major challenge for service providers. The results in the following year's survey show that the offer is being appropriately modified and adapted to meet expectations and plays a significant role in the process of promoting the region.

4.1.3. Assessment of leisure parks

In the developing tourist infrastructure of Małopolska, the offer of family amusement parks and thermal pools is very dynamic. Family trips in search of active forms of spending time together encourage the use of such forms of leisure and fun. How important this is as an element of the region's comprehensive tourist offer is illustrated by visitors' declarations regarding their main purpose of coming to Małopolska. In 2024 11% of domestic visitors surveyed indicated that this was the main purpose of their visit. Only leisure in the broadest sense was indicated more often. The offer of thermal pools used by domestic visitors, regardless of whether this was

the main or one of the purposes of their visit, was rated at 4.69. In this group of respondents, family amusement parks were slightly less popular. These facilities were the main purpose of visit for more than 6% of domestic visitors. The services on offer in the region were given a rating of 4.60. For foreign visitors, these forms of leisure and entertainment were not the priority purpose of their visit. No less than 3% declared that family amusement parks were the main purpose of their visit. Foreign visitors who visited family amusement parks gave a rating of 4.58. The rich offer of complexes and thermal pools also gained the visitors' approval and was rated at 4.50. The interest in family amusement parks and thermal pools and the highly rated offer underline the attractiveness of these complexes and their position on the tourist map of the region.

4.1.4. Evaluation of infrastructure for the disabled

Facilities for disabled travellers are a requirement of modern urban and architectural design. They are mandatorily introduced in hotel facilities, but may not be present in other accommodation facilities, where there is no obligation to introduce such solutions. Systematically introduced in public facilities, including tourist facilities, on footpaths, means of transport, service establishments, however, they are not yet a common element of tourist infrastructure. This important element of the perception of the place visited and, above all, conditioning the accessibility of places, localities or regions is being assessed by visitors. In 2024, facilities and amenities that condition people with disabilities to use the tourist offer were very well received by domestic visitors, with a score of 4.57. Such a positive perception has not been recorded in previous surveys. Foreign visitors also gave good marks to accessibility and facilities for people with disabilities, with a score of 3.99. However, given the ageing population, with the simultaneous growing need to participate in tourism, it is a necessity and duty to continuously improve all kinds of solutions conditioning accessibility for all social groups.

4.1.5. Evaluation of tourist information

The ability to take advantage of the region's tourist offer depends to a large extent on the level of tourist information and signposting facilitating access to attractions. In 2024, visitors using the services of tourist information points in Małopolska, through their rating, admitted that both access to information and the message itself met their expectations. Domestic visitors' approval was expressed in a score of 4.62, and this was the highest rating given to the information in the entire period analysed. The opinion of foreign guests about this sphere of services was also very positive, at 4.42. Maintaining a good level of the tourist information network in the region is to be commended and is the result of cooperation between regional authorities and local authorities and tourist organisations involved in the promotion of their sub-regions. Tourist information is closely linked to tourist signage, which facilitates access to tourist areas and attractions, co-creating an integrated information system. According to visitors, tourist signage also fulfilled its function, which was reflected in the high ratings given. Domestic visitors gave a rating of 4.58, which is at the level of the tourist information rating,

and foreign visitors gave a rating of 4.43. This group of respondents had not given such a high rating to signage and tourist information in previous surveys.

4.1.6. Public transport evaluation

Public transport stations: bus, train and airline stations are part of the region's assessed offer, as well as a showcase for cities and towns. In reaching the destinations visited, the organisation and service of passengers is of great importance to travellers. In 2024, all these facilities and amenities were positively evaluated by visitors. Bus stations were rated 4.0 by domestic visitors and 4.11 by foreign visitors, while the airport terminal was rated 4.18 by domestic visitors and 4.43 by foreign visitors. Only in the case of the evaluation of railway stations in Małopolska by domestic visitors was the rating lower than good and amounted to 3.95, foreign travellers were far less critical and gave a high rating of 4.42. The development of air transport, the increase in rail links and the growing interest in public transport services mean that the efficiency of services offered by railway stations/terminals will play an increasingly important role in the comprehensive tourist offer of the region.

4.1.7. Evaluation of local transport

The organisation of local transport significantly determines the accessibility of services and tourist attractions of cities, towns and the region as a whole. In 2024, domestic visitors, as in the previous year, expressed satisfaction with the local transport offer by giving a rating of 4.15. Foreign visitors' rating was even higher at 4.31. Taxi companies are also an element of local transport. The collected opinions allow us to conclude that the level of public and private transport services enabling visitors to reach their destinations and to move around within the towns and cities of the region meets the expectations of visitors to Małopolska. Access to attractions is also facilitated by parking spaces and car parks. Visitors using their own transport rated the access and level of these services. This element of tourist development and a component of the tourist offer received a score of 4.12 given by domestic visitors. Foreign visitors were more critical and rated the services offered at 3.88. This rating, although expressing full acceptance, is one of the lowest given to individual components of the region's tourist offer.

4.2. Opinion of the region

4.2.1. Place evaluation

The evaluation of a visited place is significantly influenced by the set of values referred to as the atmosphere of the place (*genius loci*) (Borkowski, Seweryn, Grabińska, 2017), a specific feature constituting its individuality, which mainly consists of widely understood historical material values and contemporary solutions and facilities characterised as tourist attractions, as well as intangible, social values expressed in the activity, hospitality and friendliness of the inhabitants. This unique element of the tourist offer invariably inspires appreciation from visitors to the region. In 2024, this was reflected in the rating of 4.73 given by domestic visitors

and 4.74 by foreign visitors. In both groups, the rating given was the highest in the entire period analysed.

4.2.2. Evaluation of tourism assets

Also, of importance in the positive perception of a visited place is the preservation of the right relationship between values, services provided and social relations. In 2024, domestic and foreign visitors, recognising the region as attractive, gave the same rating of 4.66. Also, complementary intangible values such as hospitality and friendliness of the inhabitants were appreciated by visitors, as reflected in the rating of 4.76 given by domestic visitors and 4.60 by foreign visitors. It should be noted that the region's promotion strategy focusing on cultural attractions and values is fully justified and yields positive results.

4.3. Service reviews

4.3.1. Evaluation of guide services

Visitors seeking support and enrichment of their knowledge of the region use the services of local guides, guiding at museums and sites or, in certain areas, mountain guides. In 2024, domestic visitors, like in the previous year, were satisfied with the work of guides with whom they got to know cities, towns or the region, rating their services at 4.70. Foreign visitors also had a very favourable view of the guides' work, giving a rating of 4.51. In both groups, opinions on the guides' work were higher than the average ratings obtained in the analysed period. Thus, the following research confirms that this professional group adequately reads tourists' needs and adapts to their expectations.

4.3.2. Evaluation of entertainment

The offer of the broadly defined entertainment industry significantly influences the way visitors spend their time and builds a positive image of tourist areas and destinations. In 2024, the opinion of domestic visitors on the form of entertainment provided by discos, pubs, clubs was reflected in a rating of – 4.18. In the current survey, they gave a higher rating than domestic visitors (4.31). It can be noted that opinions on entertainment services are generally positive, but the growing needs of tourists and increasing demands force them to constantly adapt their offer and take care of its level.

4.3.3. Assessment of night-time attractions

Due to the variation in the scope and form of the night-time entertainment offer, the research collected visitors' opinions on night-time attractions in a broad sense. Both domestic and foreign visitors rated night-time attractions higher than at other times of the day, giving a score of 4.34 and 4.38 respectively. However, it should not be overlooked that there is a growing problem that satisfaction with the night-time entertainment offer expressed by tourists is contradictory to the reception of this form of entertainment by local communities. In this area, it is important to monitor the phenomenon and develop solutions that satisfy both sides.

4.3.4. Evaluation of cultural events

Cultural events, music concerts or mass events are important elements that attract visitors and significantly influence the evaluation of a region's tourism offer. They are often the main destination. They shape visitors' opinions about the level of culture of a place or area. The aim of such events is to provide entertainment and to attract tourists and offer diverse cultural entertainment. In 2024, domestic visitors gave a rating of 4.36 and international visitors 4.28 and both ratings were higher than those given last year. This confirms that the cultural events on offer in Małopolska are prepared and conducted with a sense of the expectations of domestic and foreign audiences.

4.4. Opinions on tourist forms

4.4.1. Evaluation of summer and winter offer

In order to continuously improve the level of tourist attractiveness of the region, visitors opinions on the summer and winter tourist offer are solicited. Each successive year has seen an increase in positive opinions of domestic visitors about the region's summer offer. In 2024, the rating given is 4.80, which is the highest rating given by visitors to the region. The offer was also approved by foreign visitors, who gave it a rating of 4.49. It should be noted that when assessing the region's summer or winter offer, the surveyed visitors evaluate a wide range of different services included in these offers.

4.4.2. Assessment of family tourism

The region's diverse assets and attractions, extensive infrastructure, proper management and facilities for travellers with children, as well as the agritourism offer, are conducive to the development of family tourism. This form of recreation is used by 1/3 of visitors to Małopolska. It was positively received by domestic visitors, who gave it a rating of 4.35. Foreign visitors travelling with children also rated this sphere of services highly (4.12). The offer for family tourism occupies an important position in the offer of Małopolska service providers and meets the expectations of visitors. Family leisure is largely associated with the offer provided by agritourism farms. This very widespread and varied base covering comprehensive accommodation and food services, and guaranteeing a wide range of attractions and entertainment, was given a score of 4.71 by domestic visitors, and was once again one of the highest scores among all rated elements of the region's tourist offer. Foreign visitors, despite using the agritourism base less frequently, also rated the level of this offer highly, giving it a score of 4.28.

4.5. Opinions on the management of the reception site

4.5.1. Evaluation of the management of the place visited

An indicator of the level of culture and living conditions of a visited place or area is the organisation of the space, the order and cleanliness of the surroundings. These elements are easily observable and readily assessed by visitors. In 2024, the orderliness and cleanliness of

the surroundings in the visited places of Małopolska were noticed and highly rated by both domestic (4.50) and foreign visitors (4.60). This testifies to the continuing care for the surroundings by local authorities and residents themselves. However, regardless of the rating given by visitors, the statement that the cleanliness of cities, towns and areas significantly influences the opinion of the whole visited region remains valid.

4.5.2. Assessment of management and operation of public facilities

Important measures of the level of culture of the area visited also include the availability and functioning of public facilities, which include public toilets. These services in the assessed towns, places or facilities in Małopolska do not raise any objections from visitors, and their rating has remained at a similar level throughout the analysed period. Domestic visitors rated the access and cleanliness of these places at 3.68, and foreign visitors at 3.70. It can be seen that the pandemic's enforced responsibility for the sanitary condition of public places has had a positive impact on the quality of this sphere of services. At the same time, users are more sensitive and pay more attention to the observance of hygienic rules. While the sanitary condition of public toilets does not raise major concerns, the accessibility of these places is still not fully satisfactory.

4.5.3. Epidemic safety assessment

Awareness of epidemic risks is currently one of the most important aspects considered before choosing a destination. Therefore, the perception of safety in this respect in the visited place is very important. The sanitary safety component of Małopolska's tourist offer was rated at 4.20 by domestic visitors, with foreign guests giving a similar rating of 4.11. It is worth emphasising that visitors' positive perception of the level of cleanliness and hygiene of public places, which determines sanitary safety, may be an important component of promotional campaigns for the region.

4.5.4. Hygiene assessment of the place visited

The health-consciousness and growing ecological awareness of societies translates into travellers' perceptions of the quality of atmospheric air in the place visited. The opinion of visitors obtained in the surveys indicates that the quality of air in the visited towns and cities or areas of Małopolska raises no concerns. Domestic visitors gave a rating of 4.68, which is the highest rating they gave in the analysed period. Foreign visitors, who have so far had more reservations than domestic visitors, rated the air quality at 4.53. Such a positive opinion of visitors has not been recorded in previous surveys. This indicates that environmental cleanliness problems observed by local communities are not noticed by visitors to the region. The choice of places that are attractive in terms of nature and the short duration of their stay contribute to the high level of ratings. However, the statement that caring for the environment is one of the biggest challenges of any tourist destination remains valid.

4.5.5. Evaluation of Internet access

The comfort of tourists when travelling and staying in the places visited is influenced by access to the public Internet. Unquestionably, the developing Internet applications make it easier to navigate, obtain information and opinions about the places and services visited. Subsequent surveys showed that visitors found internet accessibility to be less of a problem. In 2024, domestic visitors gave this service a rating of 4.16. Foreign visitors rated Internet accessibility equally highly, with a rating of 4.24. It should be noted that Internet accessibility is currently treated not as a service, but as a natural part of the infrastructure of the place visited. Visitors' expectations of free access to the service are steadily increasing.

4.5.6. Assessing the impact of the war in Ukraine

The ongoing war in Ukraine and the persistent epidemiological threats have a very clear impact on tourists deciding where to go. Therefore, the visitors' opinion of safety in the place visited, which consequently contributes to an assessment of safety in Małopolska as a whole, is important in shaping the image of the region and promoting the places visited. It should therefore be clearly emphasised and publicised that visitors feel very safe during their stays in Małopolska, which is reflected in the rating of 4.46 given by domestic visitors. The level of safety in the visited place and region was rated even higher (4.66) by foreign visitors, who had more concerns before arriving in Małopolska than domestic travellers. It seems reasonable that such a good opinion, especially of foreign visitors, regarding safety must be used in the promotion of tourism.

5. Conclusions

Tourism infrastructure in the Małopolska Region and the issue of tourists' subjective assessment of tourism services has not yet been described and analysed in many articles. The research results presented above can in principle be referred to only one publication. However, Mazanek L., Borkowski K. and Kruczek Z. made a general evaluation of tourism services in the city of Kraków based on research conducted between 2010 and 2020 (Mazanek, Borkowski, Kruczek, 2021). The authors focused primarily on the overall perception of the urban destination by all respondents. The data presented in the aforementioned article showed that Kraków was rated by tourists as an attractive destination with a high level of tourism infrastructure until 2019 (a record pre-covid year). Relating this information to the results related to tourists' opinion of the entire Małopolska Voivodeship in the next record year 2024 (excluding the capital of the voivodeship), it should be noted that the region itself is also rated highly in terms of preparation and tourist attractiveness. In many cases these ratings are on an upward trend, so it can be concluded that Małopolska is constantly developing and adapting to new trends and the needs of demanding tourists (Borkowski et al., 2025).

Using the 'WAED' and 'ZWAD' indicators, it is possible to obtain for each segment of the tourist stream an image assessment of this type of haunted destination. A condition for the success of the assessment is a representative sample that allows generalisation beyond the sample.

The study sought to answer two key questions: do the assessments of the 21 elements influencing the quality and management of tourism in Małopolska converge or differ in the opinions of the domestic and foreign tourist populations visiting the region? And what is the reason for the differences in assessment by domestic and foreign tourists? Regarding the first question, an adequate answer would be an analysis of the Integrated Destination Attractiveness Index, which overall for both tourist populations is 4,39, which is high. The distribution by population is corresponding for domestic visitors it is 4.41 and for international visitors it is 4.37. Both indicators are high, indicating a good evaluation of the destination visited. As the differences in ratings are small, there was no basis for analysing the reasons.

The authors believe that it is worth continuing further research in this area.

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THE ROLE OF DIGITAL INITIATIVES IN ADVANCING ESG IN POLISH INDUSTRIAL COMPANIES

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Purpose: The purpose of this paper is to investigate the relationship between digital initiatives and Environmental, Social, and Governance (ESG) performance in the Polish industrial sector. The research aims to determine how the implementation of Industry 4.0 technologies contributes to corporate sustainability and supports the achievement of Sustainable Development Goals (SDGs).

Design/methodology/approach: The study adopts a mixed-method approach, combining qualitative textual analysis and quantitative statistical evaluation. Corporate sustainability reports of 15 publicly listed companies from the WIG50 index were analyzed using a predefined set of digitalization-related keywords to assess the presence and intensity of digital initiatives. Statistical analysis, including Pearson correlation and regression modeling, was used to identify relationships between digital transformation and ESG performance. The research also considers the influence of external factors, such as regulatory conditions and market competition, on digital strategy development.

Findings: The findings reveal a positive but moderated correlation between digital initiatives and ESG performance in the Polish industrial sector. Industry 4.0 technologies such as AI-driven energy optimization, IoT systems, and digital twins were found to significantly contribute to sustainability objectives. However, the results also highlight the complex nature of ESG performance, indicating that while digitalization is a key enabler, other organizational and environmental variables also play a critical role.

Research limitations/implications: The research is limited by its scope, focusing on 15 companies within the industrial sector in Poland. Future research should consider a broader dataset, use longitudinal methods, and include qualitative case studies to deepen insights into the evolving relationship between digitalization and sustainability.

Practical implications: The study offers practical insights by showing how digital transformation can enhance ESG performance. Companies can use these findings to guide strategic investment in digital technologies within sustainability and governance frameworks.

Originality/value: This paper provides novel empirical evidence on the digitalization–sustainability nexus in the Polish industrial context. It adds value by bridging the gap between digital transformation and ESG performance, and is relevant for researchers, practitioners, and policymakers interested in sustainable industrial development.

Keywords: digitalization, digital initiatives, ESG, SDG, Industry 4.0.

Category of the paper: Scientific research.

1. Introduction

The urgency of integrating sustainable practices into industrial activities has intensified in light of environmental challenges and the global push for achieving the United Nations Sustainable Development Goals (SDGs). Digital transformation is positioned as a key enabler of sustainable strategies, offering new methods for improving environmental efficiency, social engagement, and governance transparency within organizations. In the industrial sector, which traditionally carries a significant environmental and social footprint, digital technologies are increasingly recognized for their potential to drive responsible innovation. Industry 4.0 tools, such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics, and predictive maintenance systems-support not only operational efficiency but also environmental stewardship and transparent governance.

Poland's industrial companies, navigating through both digital and sustainable transitions, represent a particularly interesting context. With increasing emphasis from the European Union on the twin transition (digital and green), Polish enterprises are progressively investing in smart technologies to align with global sustainability standards. This study focuses on assessing how digital initiatives influence the Environmental, Social, and Governance (ESG) performance of Polish industrial companies and how such transformations contribute to the achievement of the SDGs

2. Linking digital initiatives with ESG performance: a literature-based perspective

2.1. Theoretical foundations of digital transformation and its role in industrial sustainability

Digital transformation has emerged as a critical area of research in information systems and strategic management, profoundly impacting industries and organizational structures (Bharadwaj et al., 2013; Piccinini et al., 2015a). Defined as a process that enhances an entity through the integration of information, computing, communication, and connectivity technologies, digital transformation extends beyond mere technological adoption. It requires firms to implement strategic and structural changes to fully realize value creation (Majchrzak, 2016; Svahn et al., 2017). Research highlights that while technology is an enabler, organizational factors such as strategy, culture, and processes play equally crucial roles in the success of digital initiatives (Vial, 2019; Matt et al., 2015; Selander, Jarvenpaa, 2016). Digitalization in especially manufacturing is increasingly recognized as a key enabler for sustainability. Previous studies have underscored the role of digital transformation in improving

eco-efficiency, operational transparency, and governance practices (Fitzgerald et al., 2014; Westerman et al., 2011). However, with the passage of time and the changes made both in legislation and the development of technology, studies of recent years show the opposite trend. The integration of digital technologies has been shown to improve eco-efficiency, reduce resource consumption, and enhance operational transparency (Zheng et al., 2020; Skender et al., 2019).

As the study aim is to research a digital initiatives in lens of industrial sector it seems necessary to describe how the current paradigm shift into Industry 4.0. Digital transformation and Industry 4.0 are central themes in contemporary sustainability research. Studies have highlighted the potential of digitalization to revolutionize manufacturing processes through technologies like smart sensors, predictive maintenance systems, and digital twins (Wang et al., 2016; Oyekanlu et al., 2020). These innovations contribute to resource efficiency, reduced environmental impact, and improved decision-making, aligning with the principles of Industry 4.0 and the emerging paradigm of Industry 5.0, which emphasizes human-centric and sustainable development (Wolniak, 2023; Verma, 2024). Nonetheless, despite these technological advancements, empirical studies that link digital initiatives directly to measurable improvements in ESG (Environmental, Social, Governance) performance remain limited, particularly in the Polish industrial context.

Research question 1 (**RQ₁**) emerges from this gap:

RQ₁: *What is the relationship between digital initiatives and overall ESG performance in the Polish industrial sector?*

Further, the ESG framework serves as a critical benchmark for assessing corporate sustainability performance. Companies with higher ESG scores often demonstrate stronger commitments to environmental stewardship, social responsibility, and governance practices (CSRHub, 2024). Previous research has established that digital initiatives, such as AI-driven energy management and IoT-enabled production systems, positively influence ESG metrics by enhancing efficiency and reducing waste (Shrouf, Miragliotta, 2015; Nabati et al., 2020).

2.2. Conceptualizing ESG-driven digitalization in the Polish industrial sector

In Europe, eco-efficiency indicators and innovations have been identified as crucial elements of sustainable industrial practices (Łącka, Brzezicki, 2022; Madden et al., 2005). The European Union has prioritized digital transformation as a strategic objective, emphasizing its role in fostering sustainable development across member states (European Commission, 2024). In Poland, the focus on Industry 4.0 is evident in studies exploring technologies like augmented reality, and virtual reality applications in manufacturing, which support energy-efficient and personalized production processes (Pizoń et al., 2023; Górski et al., 2022). In Poland, the industrial sector has been undergoing significant digital transformation. Companies are adopting digital tools and strategies to improve production efficiency and align with global sustainability standards (Grzyb, 2017). Despite these advancements, there remains

a need for empirical research linking digital initiatives to measurable sustainability outcomes, such as ESG performance and contributions to the SDGs.

The intersection of digitalization and sustainability also involves the development of predictive maintenance systems and digital twins. These approaches not only optimize production but also contribute to long-term sustainability by reducing downtime and waste (Ersöz et al., 2022; Xu et al., 2022). Additionally, research on eco-innovations and national eco-efficiency highlights the broader impact of digital initiatives on achieving SDGs at the regional level (Gałązka, 2017; Ilić et al., 2022).

Based on that it can be stated that there is a growing body of evidence suggesting that specific dimensions of ESG performance environmental stewardship, social responsibility, and governance transparency can each be individually influenced by targeted digital initiatives. However, detailed analysis regarding how specific aspects of ESG are aligned with digital transformation efforts remains underdeveloped.

This leads to the second research question:

RQ₂: *How are digital transformation efforts aligned with specific aspects of ESG, such as environmental management and governance practices?*

While prior literature underscores the transformative potential of digitalization, it also points to challenges, such as ensuring equitable access to technology and addressing the environmental costs of digital infrastructure (Yang et al., 2023). This study contributes to the existing body of knowledge by focusing on the Polish industrial sector, providing insights into how digital initiatives influence ESG performance and support the realization of the SDGs.

The existing body of research underscores the transformative potential of digitalization in manufacturing, particularly in enhancing sustainability through improved efficiency, reduced environmental impact, and better governance practices. In Poland, where the industrial sector is rapidly evolving through digital initiatives, understanding the tangible impact of these transformations on ESG performance and SDG alignment is crucial. Despite the increasing adoption of Industry 4.0 and emerging Industry 5.0 principles, there is a need for more comprehensive analyses that connect digital advancements with measurable sustainability outcomes.

To answer the two research questions, the following hypothesis is proposed:

H₁: *The introduction and development of digital initiatives at industrial companies in Poland is positively impacting their related to their ESG (Environmental, Social, Governance) performance.*

To guide the empirical analysis, a conceptual model is introduced (Figure 1). It presents the hypothesized relationship between the intensity of digital initiatives and ESG performance.

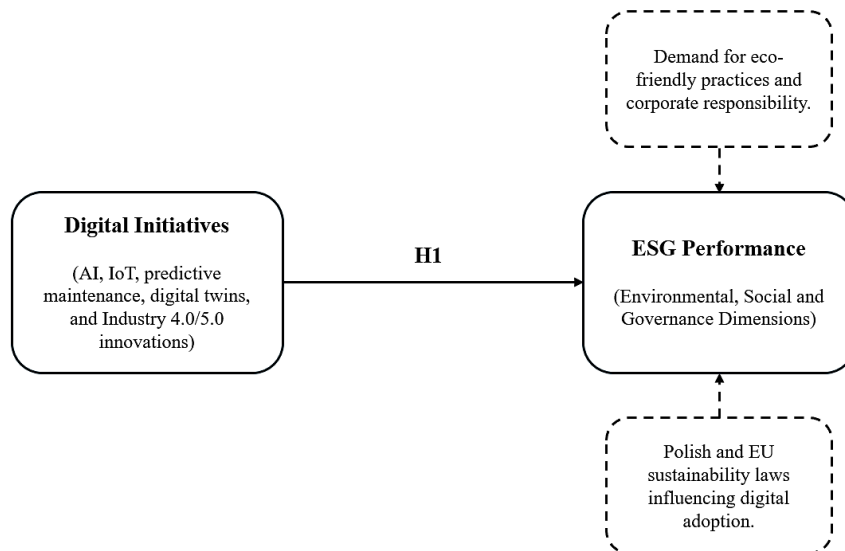


Figure 1. Conceptual model.

Source: Self-made.

Focusing on the industrial sector in Poland, a country undergoing significant economic and technological transformation, the study analyzed the ESG scores and digital initiatives of 15 Polish industrial companies listed in the WIG50 index. Using a combination of textual analysis of corporate reports and statistical methods, this study assesses the extent to which digital transformation efforts are linked to improved ESG scores and SDG alignment.

3. Methods

3.1. Sample and data collection procedure

This study investigated the relationship between digital initiatives and the achievement of Sustainable Development Goals (SDGs) in the industrial sector in Poland, hypothesizing that the introduction and development of digital initiatives in industrial companies positively impact their ESG (Environmental, Social, Governance) performance, enhancing their ability to achieve SDGs. The analysis focused on 15 industrial companies listed on the WIG50 index in 2024 by market capitalization. The ESG ratings of the selected companies were obtained from CSRHub, a platform that aggregates data from 957 sources covering 56,545 companies across 210 countries. CSRHub assigns ESG scores on a normalized scale of 0 to 100, with higher scores indicating better sustainability performance. The scores are based on four main categories:

- **Community** – evaluates a company's engagement with local, national, and global communities, considering charitable activities, respect for human rights, supplier relationships, and the social/environmental impact of its products and services.

- Employees – assesses policies on diversity, employee rights, compensation, benefits, training, health and safety, and workplace treatment.
- Environment – covers environmental compliance, resource management, climate initiatives, energy efficiency, green technology, and environmental risk management.
- Governance – analyses governance practices, including board independence, executive compensation, transparency, ethics, stakeholder engagement, and integration of sustainability into operations.

Each company's overall ESG rating was derived from scores within these categories and their respective subcategories.

To assess digital initiatives, textual analysis of companies' annual non-financial reports was performed. The analyzed documents included sustainability reports, integrated reports, and other non-financial disclosures, all downloaded directly from the companies' official websites. Textual analysis was conducted using 52 key phrases associated with digitization and Industry 4.0, identified based on the methodology of Ionaşcu et al. Python's text processing libraries, PyPDF2, Pandas, and Re, were used to extract and analyze text content, identifying the frequency of key phrases related to digitization. The results were normalized by calculating the proportion of keyword occurrences to the total word count in each document.

3.2. Methods

Statistical analysis involved the application of measures of central tendency and dispersion, including arithmetic mean, standard deviation, and minimum and maximum values. Arithmetic means provided a synthetic overview of the observed variables, while standard deviation served as a measure of variability around the mean. These measures constitute fundamental tools in descriptive data analysis and are widely used to characterize distributions and compare variability between groups (Bhaskar et al., 2019; Berry et al., 2021).

To assess the linear relationship between the level of digitalization and ESG performance, Pearson correlation analysis was employed. The Pearson correlation coefficient measures the strength and direction of a linear relationship between two continuous variables (Schober, Boer, Schwarte, 2018). Subsequently, linear regression analysis was conducted to examine the potential predictive effect of the independent variable (digital initiatives) on the dependent variable (ESG scores). Linear regression enables the modeling of relationships between variables and allows the prediction of the dependent variable based on values of the independent variable (Yan, Su, 2009).

Prior to conducting parametric analyses, the assumption of normality was verified using the Shapiro-Wilk test. A critical consideration in applying this test is the minimum sample size required for reliable results. According to the findings of Bartkowiak and Słowik (2016), the Shapiro-Wilk test can be effectively applied to samples as small as six observations. Its selection in this study was therefore justified by its high statistical power in small samples

and its widespread application in quantitative research. This test was used to verify the following two null hypotheses:

Null hypothesis 1 (H_{01}): The distribution of the data is a normal distribution.

Null hypothesis 2 (H_{02}): The correlation coefficient in the population is equal to 0 (i.e., there is no correlation between the two variables).

Statistical analysis was conducted in Python within the Jupyter Notebook environment, utilizing libraries such as NumPy, Pandas, SciPy, Statsmodels, and Scikit-learn.

3.3. Hypothesis Testing

The central research hypothesis of this study states:

H_1 : *The introduction and development of digital initiatives at industrial companies in Poland is positively impacting their related to their ESG (Environmental, Social, Governance) performance.*

To empirically verify this hypothesis, a parametric approach was adopted. The testing procedure consisted of two stages: (1) testing the assumption of normality and (2) examining the statistical relationship between variables through correlation and regression analysis.

In the first step, the Shapiro-Wilk test was applied to evaluate whether the ESG score data followed a normal distribution. The null hypothesis (H_{01}) assumed normality. A p-value greater than 0.05 would indicate that there is insufficient evidence to reject H_{01} , thus permitting the use of parametric tests such as Pearson's correlation and linear regression.

Subsequently, the strength and direction of the relationship between digital initiatives and ESG performance were tested using Pearson's correlation coefficient. The second null hypothesis (H_{02}) posited that there is no correlation between the two variables ($r = 0$). If the resulting p-value is less than or equal to 0.05, H_{02} is rejected, supporting H_1 and indicating that digital transformation is significantly associated with ESG outcomes.

Finally, simple linear regression analysis was used to assess the potential predictive power of digital initiatives. If the regression coefficient is statistically significant ($p \leq 0.05$), it confirms that digital initiatives contribute meaningfully to variations in ESG scores—thereby supporting the hypothesis that digitalization enhances corporate sustainability performance in the industrial sector.

In this study, the reliance on self-reported data from industrial companies poses potential challenges to the validity and objectivity of the findings. Specifically, the analyzed ESG scores and annual reports may reflect biases inherent to self-reporting practices. Companies often aim to present themselves in a favorable light to stakeholders, potentially overstating their ESG performance or selectively highlighting digital initiatives that align with sustainability goals. This risk of "greenwashing" could impact the accuracy of the correlations observed between digital initiatives and ESG performance. To address these challenges and increase the credibility of the survey results, mitigation strategies were employed. The study used ESG scores provided by CSRHub, a recognized and independent ESG rating platform that aggregates

data from more than 900 reliable sources. This provided a broader perspective and reduced reliance solely on company-reported indicators. Text analysis of non-financial reports was conducted using a pre-defined and revised list of 52 key phrases identified in earlier academic research. By focusing on unambiguous and consistent terminology, the risk of subjective interpretation of textual data was minimized.

4. Results

Analysis of the results begins with basic descriptive statistical analysis including arithmetic mean, standard deviation, minimum and maximum values. Arithmetic means were calculated to provide a summary measure of the central tendency of the observed data, while standard deviations were used to quantify the variability and dispersion around the mean. For ESG scores, a higher standard deviation indicates greater variability in the results, reflecting a wider spread of values and suggesting a higher degree of diversity within the dataset (Table 1). Conversely, for the proportion of words related to digitization, a lower standard deviation indicates that the values are closely clustered around the mean, signifying that the mean provides a more accurate representation of the entire sample.

Table 1.
Statistical analysis of ESG results and digital initiatives.

Variable	Arithmetic mean	Standard deviation	Minimum	Maximum
ESG score	45.87	19.44	18	77
Digital initiatives	0.0477	0.0398	0.0100	0.1254

Source: Self-made.

The null hypothesis for the Shapiro-Wilk Test (H_{01}) posits that the data follows a normal distribution. The results of the test yielded a **p-value of 0.0716**, which exceeds the **conventional significance level of 0.05**. This indicates insufficient evidence to reject the null hypothesis, implying that the data distribution is consistent with normality. Consequently, we can assume that the ESG scores are normally distributed, an important assumption for the validity of subsequent parametric analyses, such as correlation and regression, which rely on the normality of the data. This finding supports the robustness and interpretability of the correlation analysis and strengthens the reliability of the results presented in subsequent statistical tests (Table 2).

Table 1.
Shapiro-Wilk test results

Variable	Statistic	p-value
ESG score	0.8919	0.0716*
*Note: $p > 0.05$ indicates no significant deviation from normality.		

Source: Self-made.

Next, Pearson's correlation coefficient was calculated to examine the relationship between ESG scores and the proportion of digital initiatives mentioned in the reports. The null hypothesis for the correlation analysis (H_{02}) assumes that there is no correlation between the two variables. The Pearson correlation coefficient between ESG scores and digital initiatives was found to be 0.552 (Table x), indicating a moderate positive correlation. This means that as digital initiatives increase in the annual reports of industrial companies, their ESG ratings tend to increase as well. Although the correlation is not strong enough to assert a robust relationship, it does suggest a meaningful association between the variables.

The significance level for the Pearson correlation (Table 3) was found to be $p = 0.032$, which is less than the threshold of $p = 0.05$. This allows us to reject the null hypothesis and conclude that **there is a statistically significant correlation between digital initiatives and ESG performance**. Therefore, we can confidently reject the null hypothesis at the 95% confidence level.

Table 2.
Pearson Correlation Analysis

Variable	ESG score	Digital initiatives
ESG score	1.00	
Digital initiatives	0.552*	1.00
*Note: $p < 0.05$ indicates a statistically significant correlation.		

Source: Self-made.

The research hypothesis posited that **there is a relationship between digital initiatives in the industrial sector and the achievement of the SDGs, as assessed by ESG scores**. Based on the results, we can conclude that there is a moderate, statistically significant positive correlation between the digital initiatives undertaken by industrial companies and their ESG performance.

The regression analysis further elucidates the relationship between the independent variable, "Digital initiatives", and the dependent variable, "ESG score". The directional coefficient of the regression line (269.92) indicates that for every one-unit increase in digital initiatives, there is an associated increase of 269.92 units in the ESG score, assuming all other factors remain constant. This finding underscores the positive impact of digital initiatives on ESG performance, reinforcing the hypothesis of a significant relationship between these variables.

Table 3.
Regression Coefficient Analysis

Variable	Regression Line Coefficient	t-Statistic	p-Value	R ²	Adjusted R ²
Digital initiatives	1.00	2.387	0.033*	0.305	0.251
*Note: $p < 0.05$ indicates a statistically significant correlation.					

Source: Self-made.

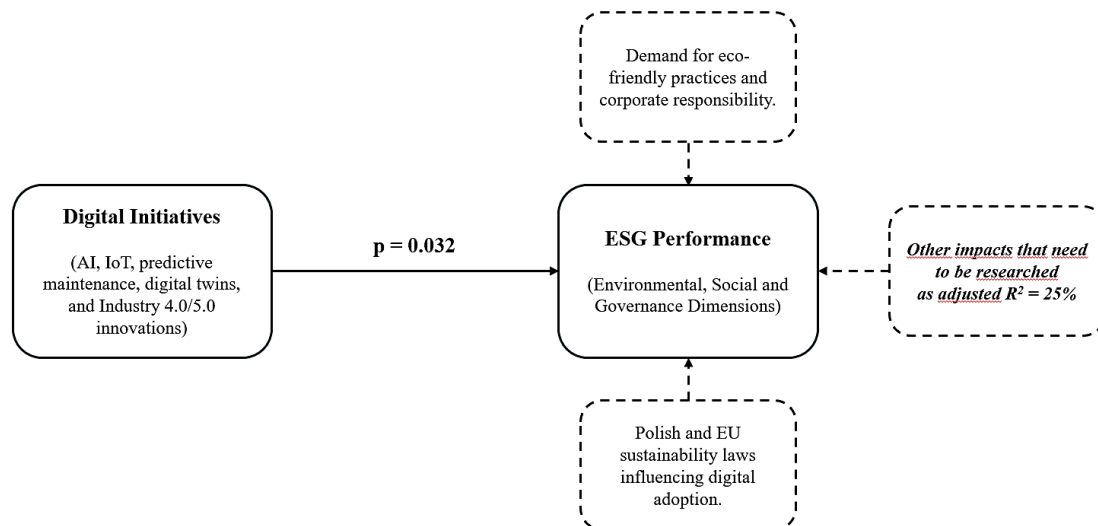


Figure 2. Correlation visualization on the conceptual model.

Source: Self-made.

The adjusted R^2 value of 0.251 (Table 4) suggests that the model accounts for approximately 25.1% of the observed variability in ESG scores. While this indicates a statistically significant relationship, the relatively low value of the adjusted R^2 highlights that a majority of the variability in ESG scores is attributable to factors not captured by the model, but also the one included as potentially impacting it. This underscores the complexity of ESG performance, which is likely influenced by additional variables such as industry-specific practices, regulatory compliance, and broader economic conditions.

These findings point to the potential of digital initiatives as a contributing factor to ESG improvement, while also emphasizing the need for a multifaceted approach to understanding and enhancing sustainability outcomes. Future models could incorporate additional predictors to better capture the complexity of ESG performance dynamics.

5. Discussion and contribution

The results of this study provide empirical evidence supporting the hypothesis that digital initiatives in Polish industrial companies are positively associated with their ESG performance, thereby contributing to the realization of Sustainable Development Goals (SDGs). The Pearson correlation coefficient (0.552) and regression analysis results indicate a moderate but statistically significant relationship between the extent of digitalization efforts and ESG scores.

When comparing these findings with existing literature, the results align with previous research highlight the role of digital transformation in enhancing eco-efficiency and sustainability performance. Furthermore, the study is consistent with European trends emphasizing digitalization as a key enabler of sustainable industrial practices. However,

the relatively modest adjusted R² value (0.251) suggests that ESG performance is influenced by multiple factors beyond digital initiatives alone, including regulatory policies, corporate culture, and external economic conditions.

The positive correlation between digital initiatives and overall ESG scores supports earlier propositions that digital transformation acts as a critical enabler of sustainable practices within organizations (Bharadwaj et al., 2013; Piccinini et al., 2015a). By integrating smart technologies into manufacturing and management processes, companies appear to enhance not only operational efficiency but also social and governance standards, a finding consistent with the works of Majchrzak et al. (2016) and Svahn et al. (2017a), who emphasized the necessity of organizational adaptation alongside technological adoption.

The results also resonate with the broader theoretical frameworks of Industry 4.0 and the emerging Industry 5.0 paradigm (Wang et al., 2016; Oyekanlu et al., 2020; Wolniak, 2023; Verma, 2024). The evidence from the Polish industrial sector suggests that digitalization efforts not only optimize production processes but also support broader sustainability objectives, consistent with the human-centric, resilient industrial models proposed in recent literature.

Nevertheless, despite the positive association between digital initiatives and ESG performance, the relatively moderate strength of the correlation indicates that digital transformation is not the sole determinant of sustainable development success. This is consistent with earlier assertions that achieving superior ESG outcomes requires a multifaceted approach, including strong leadership, regulatory compliance, employee engagement, and transparent governance structures (Yang et al., 2023).

Furthermore, the study's results reinforce previous claims about the environmental benefits of digitalization. The observed trends toward higher ESG scores among firms undertaking digital initiatives reflect the findings of Fitzgerald et al. (2014) and Westerman et al. (2011), who argued that digital technologies such as IoT and AI systems significantly contribute to eco-efficiency and resource management. In this context, the positive relationship identified in the Polish industrial sector illustrates the tangible impact of these technologies on corporate sustainability performance.

At the same time, the research does not clearly indicate the causal nature of the correlation studied. At this point, we cannot clearly determine whether digital transformation is the cause of enhancing ESG, or whether there is an inverse relationship.

In light of the study's findings, several practical recommendations can be proposed to support the effective alignment of digital transformation with ESG objectives in the Polish industrial sector. First, industrial companies should integrate ESG criteria directly into their digitalization strategies. Rather than treating sustainability as a separate initiative, organizations can embed environmental, social, and governance considerations into digital investment decisions. This includes selecting technologies not only for efficiency but also for their potential to reduce emissions, improve transparency, and promote employee well-being.

To ensure coherence across departments, companies are encouraged to establish cross-functional teams involving IT, sustainability, and operations units. These teams can collaboratively develop and monitor digital projects that deliver measurable ESG outcomes. Additionally, organizations should implement internal governance mechanisms, that support real-time tracking and accountability.

From a policy perspective, there is a strong rationale for governmental support of ESG-oriented digitalization. Incentive programs for companies that adopt digital technologies aligned with sustainability goals could accelerate the twin transition agenda. Moreover, regulatory bodies may consider developing standardized ESG reporting templates that integrate digital indicators, thus improving transparency and benchmarking across the industrial landscape.

Small and medium-sized enterprises (SMEs), which often face resource constraints, should be supported through dedicated programs that provide access to shared digital infrastructure and targeted training in ESG-compliant technology use. Public-private partnerships can play a vital role in reducing these barriers.

Altogether, the alignment of digital transformation with ESG principles requires a coordinated approach involving corporate leadership, technical innovation, and supportive public policy. These recommendations aim to facilitate not only compliance with evolving sustainability standards but also long-term competitive advantage through responsible and forward-looking industrial strategies.

6. Limitations

Despite these promising results, the study acknowledges certain limitations, including potential biases in self-reported data and the influence of external factors not accounted for in the model. While the first of this limitation is mitigated by use of CSRHub, future research could incorporate additional independent sustainability assessments to validate the findings further. Another consideration is the sample size, as the study focuses on 15 industrial companies listed in the WIG50 index. Expanding the sample to include more firms from diverse sectors would enhance the generalizability of the results. Future research could also expand the scope to include all WIG50 companies and explore alternative methodologies such as case studies or in-depth interviews.

Future research could also explore causal relationships by conducting longitudinal studies or leveraging machine learning techniques to analyze patterns in digital adoption and ESG performance over time. Additionally, qualitative analyses, such as interviews with industry leaders, could provide deeper insights into the strategic motivations behind digitalization efforts and their perceived impact on sustainability. By addressing these aspects, future studies can

offer a more nuanced understanding of the intersection between digitalization and sustainable development in the Polish industrial sector. It is also worth mentioning that the relatively low adjusted R^2 value suggests that while digital transformation plays a role in enhancing ESG performance, additional variables contribute to sustainability outcomes.

7. Conclusion

This study examined the relationship between digital initiatives and ESG performance in the Polish industrial sector. The findings indicate a moderate yet significant positive correlation between digital transformation efforts and ESG scores, supporting the hypothesis that digital initiatives contribute to sustainability improvements. The regression analysis further confirms this relationship, showing that increased digitalization is associated with higher ESG scores.

Despite these promising results, the study acknowledges certain limitations, including potential biases in self-reported data and the influence of external factors not accounted for in the model. The relatively low adjusted R^2 value suggests that while digital transformation plays a role in enhancing ESG performance, additional variables contribute to sustainability outcomes.

Future research should expand the scope to include all WIG50 companies and explore alternative methodologies such as case studies or in-depth interviews. Additionally, incorporating time-series analyses could help determine whether the impact of digital initiatives on ESG performance strengthens over time. By addressing these aspects, future studies can offer a more nuanced understanding of the intersection between digitalization and sustainable development in the Polish industrial sector.

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AUTHENTICITY AS BRAND MANAGEMENT TOOL IN SOCIAL MEDIA

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Purpose: The aim of this article is to define how marketing practitioners understand, design and apply an authenticity strategy in brand communications on social media

Design/methodology/approach: The study is exploratory and qualitative in nature and was based on conducting 15 individual in-depth interviews (IDI) with communication and marketing managers representing various industries. The data was subjected to thematic analysis using an inductive approach.

Findings: The survey results indicate that authenticity is perceived as a strategically constructed narrative, the implementation of which is subject to institutional constraints. Respondents point to the need to adapt forms of authenticity to the characteristics of platforms (e.g., TikTok vs. LinkedIn) and to the presence of tensions between the need for sincerity and image control.

Research limitations/implications: The study is exploratory and qualitative in nature and is based on qualitative analysis of in-depth interviews with a limited, purposively selected sample of 15 respondents, so the results cannot be generalized. Furthermore, the dynamic nature of social media means that the results must be interpreted in relation to a specific moment in time – changing platform trends or cultural expectations may influence the redefinition of authenticity practices in the coming years.

Practical Social implications: The results of the study provide a number of practical tips for those responsible for communication strategy and brand management in the digital environment. Authenticity requires planning and competence, not improvisation - effective authenticity management is not about spontaneity, but about skillfully constructing a message that meets cultural and platform norms while maintaining credibility.

Originality/value: This article brings a new perspective to authenticity research by focusing on the perceptions of practitioners responsible for social media communication. The research identifies how they understand and implement the authenticity strategy and what practical tensions between strategic communication and the perception of authenticity they manage in this area.

Keywords: brand authenticity, social media, marketing communication, image management, communication strategy, qualitative interviews.

Category of the paper: A research article presenting the empirical results of qualitative research in the area of brand management and communication in social media.

1. Introduction

Modern organizations operate in a communication environment characterized by a high degree of transparency, information redundancy and growing social expectations regarding ethics, coherence and credibility of actions. In conditions of intense information competition and changing cultural norms, brand authenticity becomes not only an ethical postulate, but also an important strategic resource (Beverland, 2006; Napoli et al., 2014). Social media, which are now a key tool for marketing communication, have radically transformed the way of building relationships between a brand and its stakeholders. On the one hand, they enable direct, dialogical and often informal interaction with recipients; on the other hand, they generate risks related to immediate verification of the authenticity of the organization's declarations and actions (Marwick, Boyd, 2011; Enli, 2015). In this context, authenticity ceases to be a clear-cut category, but becomes a negotiated, dynamic phenomenon, dependent on the communication platform, organizational structure, and recipients' expectations.

The purpose of this article is to examine how representatives of the marketing community define, understand, and implement the concept of authenticity in the context of brand communication in social media. The study is based on a qualitative analysis of in-depth interviews conducted with practitioners from various sectors of the economy. The authors intend to capture both communication strategies and the constraints and tensions that managers encounter in the process of managing authenticity.

The originality of the study lies in shifting the focus from the recipient to the sender, breaking away from the consumer perspective dominant in literature. The article shows brand authenticity as a consciously managed organizational process, not a spontaneous feature of communication.

The article consists of five parts. This introduction is followed by a literature review, which discusses the current approaches to authenticity in marketing and social media. The methodological assumptions of the study and the description of the research procedure are presented. The fourth part presents the results of the empirical analysis, while the final part contains conclusions, practical implications, and suggestions for further research directions.

2. Literature review. Authenticity as a communication category in marketing through the prism of social media

In literature, authenticity is defined as the coherence between the communicated values of a brand and its actual operation, history and the way it functions in the social and cultural context (Beverland, 2006; Napoli et al., 2014). This concept has gained particular importance

in an era of growing distrust towards traditional advertising and corporate communication - consumers increasingly expect brands to be transparent, consistent with their own values and have a human tone of voice (Holt, 2002). Authenticity can be designed and managed (Beverland, Farrelly, 2010) and be implemented as part of the branding strategy. A brand does not have to be objectively true; it is enough to be perceived as credible, which requires a coherent narrative, aesthetics and communication. Authenticity has evolved from being a permanent, inextricably and unequivocally linked to the brand to a constructivist form that requires constant adaptation to the relationship between the brand and the recipient. Authenticity does not exist independently of social context or interpretive intentions, it becomes an effect of the style, tone and rhetoric of communication rather than a state of reality. The advent of social media has changed the nature of the relationship between brand and audience, introducing a new framework of authenticity based on immediacy, speed of interaction, and the possibility of exposing the behind-the-scenes of action. In this context, authenticity is often associated with informality, transparency, emotional truth, and real-time response (Marwick, Boyd, 2011). Social media users are sensitive to any signs of insincerity, artificiality or exaggeration (Lee, Eastin, 2020). The presence of errors, spontaneity and lack of perfection are sometimes assessed as signs of a brand's authentic character (Abidin, 2016; Luoma-aho, 2015). This phenomenon is particularly visible on platforms such as TikTok, where the aesthetics of imperfection and narratives based on a self-deprecating tone constitute a communication norm. Enli (2015) notes that digital authenticity is contextual in nature and is closely linked to the platform on which it is displayed. What is perceived as honest on one platform may be considered unprofessional or inappropriate in another. Authenticity in social media is therefore not a universal category, but requires adaptation to the aesthetic, cultural and technological expectations of a given media community. In this context, Lehman et al. (2019) emphasize the relational nature of authenticity, assuming that its assessment depends not only on the intentions of the sender, but on the construction of meanings in interaction with recipients. The credibility of brands is built not by declarations themselves, but by the continuity of experience - the impression that the brand behaves in a way consistent with what it previously promised and how it presented itself.

There is a growing importance of adaptive brand management models that consider the variability of the platform context, diverse communication norms and the dynamic expectations of social media users. Previous research on authenticity in marketing has focused primarily on consumers' perception of brands and the psychological conditions of receptions (Morhart et al., 2015; Lee, Eastin, 2020). According to the existing literature, there is a lack of empirical studies analyzing how brand authenticity is operationalized from the perspective of communication practitioners, particularly in the context of platform specific strategies.

3. Methods

The aim of this article is to show how marketers define and implement brand authenticity in practice based on activities carried out in social media. The research, the results of which are discussed in this article, was conducted based on an original research procedure. The research procedure used is presented in Table 1.

Table 1.
Research procedure

Lp.	Task	Methods and tools used
1	Conceptualization of the research area and identification of the research problem	Critical analysis of literature
2	Operationalization of the research process	Critical analysis of literature
3	Selection of the research sample	Purposeful selection of the research sample
4	Implementation of empirical research	Individual interviews with a script
5	Data transcription and coding	Coding of speech transcription
6	Verification and naming of topics	Semantic text analysis, comparative analysis
7	Development of results and conclusions	Synthesis and conclusions

Source: own study.

The first stage was a critical analysis of the literature, based on which the research area was outlined, and the research objective was specified. The research conducted was exploratory and qualitative in nature, which corresponds to the objective defined as an in-depth understanding of the complex and contextual phenomenon of authenticity of maki in social media from the perspective of marketing practitioners. The approach used allowed for capturing the meanings, interpretations and strategies used by respondents in real market conditions.

The study was conducted from January to March 2025. The selection of the research sample was adapted to the qualitative study and its purpose, and was therefore purposeful (Babbie, 2009; Creswell, 2013; Nowak, 2012). The study included 15 participants-practitioners in independent positions in marketing and/or brand communication in social media. All participants of the study had: at least 2 years of experience in brand management, direct participation in conducting communication in social media (FB, Instagram, TikTok, LinkedIn, YouTube, etc.) and represented organizations active in communication in social media. Data were collected using semi-structured in-depth interviews (IDI), conducted via remote communication tools (Zoom, MS Teams) or in person – depending on the respondent's preferences. A single interview lasted from 45 to 60 minutes and was conducted based on a previously prepared scenario. The topics of the scenario included:

- a) Understanding authenticity in the context of branding and social media.
- b) Communication practices that promote authenticity.
- c) Challenges and tensions between authenticity and marketing objectives.
- d) Differences in perception of authenticity across platforms.

The data collection process was based on quality assurance principles (Miles, Huberman, Saldana, 2013):

1. Authorization of quotes-selected fragments of statements were sent to respondents for approval.
2. Researcher reflexivity – at each stage a research journal was kept, recording observations, coding decisions and possible changes in the analytical approach.

The principle of theoretical saturation was applied – interviews were conducted until no new threads relevant to the research problem appeared. The study was conducted in compliance with the principles of research ethics. Each participant received information about the purpose of the study, the voluntary nature of participation and the right to withdraw at any stage. Informed consent to participate and to record the interview was obtained. Data was stored in accordance with the requirements of the GDPR and personal data security standards. All interviews were recorded, then transcribed and anonymized.

The collected material (over 120 pages of transcripts) was subjected to thematic analysis using an inductive approach, in accordance with the Braun and Clarke (2006) methodology. As a result of coding, 58 open codes were distinguished, which were then grouped into 12 intermediate categories and 4 main analytical themes, constituting the basis for a discussion of the results. The applied approach made it possible to capture the individual experiences of respondents and capture the diversity of strategies used in brand communication in social media.

4. Results

4.1. Authenticity as a deliberately constructed strategy

Brand authenticity appeared in the literature as a feature accompanying other brand features such as coherence, true origin, and compliance of activities with declared values (Morhart et al., 2015; Sodergren, 2021; Cinelli, Le Boeuf, 2020; Schallehn et al., 2014).

In the era of social media, this approach has evolved. Increasingly, authenticity does not mean “truth” in an objective sense, but the construction of a message that is to be perceived as true by the recipients (Grayson, Martinec, 2004; Sodergren, 2021; Lehman et al., 2019). In the literature covering contemporary approaches to marketing strategies, the concept of strategic authenticity even appears (Sodergren, 2021; Lehman et al., 2019), where brands design narratives based on apparent spontaneity, using emotions, imperfections and personal stories – but within a conscious branding strategy (Beverland, 2009; FischerAppelt, Dernbach, 2022). There is a related phenomenon called staged authenticity, where naturalness is the result of a script, not a coincidence. In the study, respondents overwhelmingly indicated that

authenticity in brand communication is a product of planning. On the one hand, they emphasized the importance of honesty, naturalness, and “being yourself”, on the other – they admitted that every element of such a narrative is subject to strict control.

„What we present as ‘natural’ is often the result of very deliberate work. Authenticity is a branding tool today – but it has to be done skillfully so that it doesn’t look fake” (R4, communications manager, FMCG).

Comment: Respondent reveals discrepancy between content and design process – “naturalness” is planned.

„We have a ready strategy for ‘being ourselves’. Someone wrote it, approved it and is implementing it. This is not spontaneity, this is conscious impression management” (R12, marketing manager, start up).

Comment: The respondent indicates that ‘authenticity’ is standardized and embedded in the processes.

„We have a checklist of things that must be included in an ‘authentic’ post. Authenticity is a bit of a theatre where you have to act really well” (R2, social media manager, advertising agency).

Comment: Respondent reveals authenticity as a game of appearances that requires skill and direction.

The topic of recipients’ expectations also emerged – respondents admitted that their activities are designed to respond to the social demand for “honesty”, but within the limits set by the brand.

„We operate in a world of filters. People know it's a game anyway - but they want it to be a game they can believe in” (R8, online marketing manager, beauty industry).

Comment: Suggests that authenticity is more of an illusion of belief than a fact.

4.2. Formats and platforms that support authenticity.

As social media platforms evolve, the way brands communicate their identity and authenticity is changing. The literature on the subject notes that different communication formats—such as stories, reels, livestreams, and short videos—affect the perception of message credibility (Safitri, 2022). Social media favors appearing as an “ordinary person”, which leads to a model of so-called performed authenticity (Taylor, 2022). Audiences reward rawness and imperfection because they perceive it as more honest and relatable. In the context of brands, authenticity has become closely linked to using formats that emulate the everyday and the immediate, such as unedited photos, backstage, selfies and “hands-on” statements or live broadcasts. At the same time, the impression of authenticity is created by the correspondence between the style of the message, the expectations of the audience and the technological possibilities of the platform.

Survey respondents were very clear in pointing out that certain content formats and social media channels support perceived authenticity better than others. The most frequently mentioned were:

- a) TikTok-as a space for natural expression, dynamic content and humor.
- b) Instagram Stories-for its informal character and the “here and now effect”.
- c) Livestreaming-as the most difficult to control forms of communication.

„TikTok promotes what looks imperfect. If something is polished, you can immediately see that it's an advertisement. There, it's more important and more profitable to be funny than professional” (R10, digital marketing manager, educational industry).

Comment: The respondent indicates a change in the hierarchy of communication values - professionalism is giving way to naturalness.

„Stories are like backstage - we show work in progress, sometimes something doesn't work out, but that's what builds trust. People like to watch behind the scenes, because then they feel they have access to something real” (R3, social media specialist, beauty industry).

Comment: Pointing out the psychological effect of “intimate access” as an authenticity strategy.

„Live is a bit like improvisation - you can't fully control it, so paradoxically it is live performances that provide the greatest authenticity” (R11, content specialist, advertising agency).

Comment: Live is understood here as a form of exposure without a mask, which translates into greater trust.

At the same time, some respondents noted that authenticity does not always depend on the format itself, but on how the brand uses it:

„You can have reels that are totally inauthentic - if they are too studied. Format is not enough - tone and intention matter” (R7, content manager, fashion industry).

Comment: Authenticity is not only about form, but also about content and presentation - it depends on the coherence of the narrative.

4.3. Tensions Between Authenticity and Image

Authenticity in literature (Bruhn et al., 2012) indicated as one of the values of contemporary marketing communication that a brand should be guided by. It is a factor influencing the building of trust, loyalty, and engagement of recipients. At the same time, the literature on the subject indicates the existence of significant tensions between authenticity and corporate image, especially in the context of organizations with a high level of formalization of communication. Such a phenomenon is referred to as the paradox of authenticity - the greater the effort of the organization to be perceived as authentic, the more pronounced the constructive nature of the message becomes, which may result in a weakening of credibility. In this context, authenticity ceases to be a spontaneous and emotional characteristic, but becomes an element of strategic calculation, closely linked to image goals.

Brands operating within rigid procedures and complex communication structures often encounter difficulties in implementing an authentic message that simultaneously meets corporate, legal and reputational requirements. As a result, a contradiction arises between the expected freedom of communication and the need to maintain control over content.

The survey respondents emphasized that authenticity, although considered an important value in declarative terms, is sometimes limited in practice by organizational structures for controlling the message. They indicated that freedom of speech in social media is limited by approval procedures, communication policy or fears of potential image crises.

„The board says: show a human face, but only if that face is well-combed and won't say anything controversial. It's a controlled authenticity” (R5, brand manager, IT industry).

Comment: The conditionality of the message has been indicated - acceptable sincerity is defined by image norms.

„We have to consult with the legal department at every step. So even if something looks spontaneous, it's gone through three revisions. That kills some of the truthfulness that's at stake” (R15, marketing manager, banking industry).

Comment: The difficulty of reconciling authenticity with legal constraints and crisis management in the context of PR was pointed out.

„Recently, there was an opportunity where we could show ourselves, we knew how to react - empathetically and humanely, to show the face of the brand that we want, but we were waiting for acceptance. Late, we showed ourselves as imitators, cold and studied, that was not the point at all” (R14, communication specialist, beauty industry).

Comment: The formal nature of the content production process has been pointed out, even those stylized as authentic.

4.4. Authenticity as a Context- and Platform-Dependent Phenomenon

Contemporary research on brand communication in the digital environment emphasizes that authenticity is not a universal category, but rather a relational social construct, dependent on the specificity of the medium, communication style and cultural expectations of the recipients. (Lehman et al., 2019; Luoma-aho, 2015). In the context of social media, authenticity is not permanently assigned to a brand or content, but results from adapting the message to the communication norms characteristic of a given platform (Enli, 2015). What may be perceived as honest and direct on one platform may be perceived as unprofessional or inconsistent with user expectations in another environment. According to Boyd (2014), users of different platforms develop distinct cultural, aesthetic, and linguistic codes that determine acceptable forms of expression. For brands, this means adapting authenticity to the technological and social context of each communication channel, rather than using a single, unified strategy.

„(...) on TikTok there is more ease, humor, imperfection. It works there. But the same material on LinkedIn would look like a joke or amateurism” (R3, social media specialist, beauty industry).

Comment: The importance of platform culture as a factor regulating forms of authenticity is highlighted.

„Instagram still requires aesthetics. We can be “real,” but that realness has to be visually coherent and pleasing. We won’t post a selfie with bad lighting” (R6, social media manager, beauty industry).

Comment: The conditionality of authenticity was indicated, subordinated to the aesthetics of the medium.

„LinkedIn is a place where authenticity must have substantive value. There, it is not enough to show the backstage, you must have something to say as a professional” (R9, head of PR, FMCG industry).

Comment: The difference between emotional and expert communication was highlighted.

„YouTube content can be more narrative - people expect a story there. But if we are too formal, the audience loses interest. It is an authenticity that is more narrative than impressionistic” (R1; communication specialist, banking industry).

Comment: It has been pointed out that the length and depth of content determine truthfulness.

„(...) we use multiple authenticity strategies: a different set of languages for TokTok, another for Instagram, another for LinkedIn. Each channel has its own version of being yourself” (R7, content manager, fashion industry).

Comment: the need for a differentiated approach depending on the medium was emphasized.

5. Discussion

The results of the conducted qualitative research allow for an in-depth reflection on the ways of understanding and implementing authenticity in brand communication in social media from the perspective of practitioners. The analysis of the empirical material confirms the findings of previous authors, but also reveals new aspects and relationships, that bring a new perspective to the literature.

According to Beverland and Farrelly (2010), authenticity is not an objective or spontaneous feature, but the result of a planned communication strategy, stylized as naturalness and consistent with the image goals of the organization. The respondents’ statement clearly indicates that messages considered ‘natural’ are the result of a conscious selection of content, language and format, and not random actions. Thus, our findings confirm the presence of the phenomenon of so-called strategic authenticity-understood as a form of managed impression, balanced between professionalism and freedom of expression. This conclusion is also consistent with the concept of authenticity paradox (Molleda, 2010), which indicates the tension

between the desire for sincerity and the need to maintain image consistency. Respondents-aware of the recipients' expectations of transparency and naturalness operate within institutional constraints that significantly affect the possibility of fulfilling these expectations. In this context, authenticity is not only a function of external communication, but also a phenomenon conditioned by the internal organizational structure and culture of the company. Especially in large corporate organizations, authenticity often takes the form of simulated naturalness, within the boundaries set by the institution. This mechanism corresponds to the concept of managed transparency (Bernstein, 2016), according to which openness and emotionality are subject to strict managerial control.

The media context plays an equally important role. The study confirms that authenticity is relational and environmental-which is consistent with the findings of Lehman et al. (2019) and Enli (2015), who emphasized that each social media platform imposes its own interpretive framework, defining which forms of communication are perceived as authentic and which as artificial or inadequate. Respondents noted that the same message can build credibility in one medium (e.g. TikTok) and be perceived as inprofessional in another (e.g. LinkedIn). Consequently, implementing an authentic strategy requires a high level of reflexivity and communication flexibility. The respondents' statements also point to the phenomenon of aestheticization of authenticity-a situation in which even imperfection in the message must be aesthetic, consistent with the brand's visual identification and coherent with its narrative. In this approach, naturalness becomes another convention-a requirement written into the rules of communication (Knaller, 2012; Degal, Hartman, 2021). Respondents indicated the presence of controlled imperfection as a communication pattern-aesthetic austerity, apparent improvisation, or visual roughness – which strengthen the sense of sincerity. At the same time, it was emphasized that effective implementation of the authenticity strategy does not mean giving up control, but rather its transformation: from content control to emotion and form management. This approach corresponds to the concept of performative authenticity (Shtern, Hill, Chan, 2019), according to which not only “what” and “why” are important, but also “how” and “where” it is communicated.

The research also confirms the observations of authors such as Taiminen (2015) that effective authenticity in the digital space cannot be based on a universal model, but must be adapted to the specificity of a given medium and its community. In this sense, authenticity appears as a construct that is not only relational, but also situational – emerging in the interaction between sender, platform and recipient.

In summary, this study contributes an operational perspective to the literature – showing how authenticity is actually implemented in organizations, what constraints it entails, and how it varies across media. It reveals a new field of tension: between the need to be “real” and the requirement for consistency, between expression and strategy, between imperfection and aesthetics. Unlike previous studies focused mainly on audiences (Morhart et al., 2015; Napoli et al., 2014), this study focuses on the decision-making logic and everyday practices of brand

communicators. As a result, it provides a new understanding of the phenomenon of authenticity – as a dynamic trade – off that requires both empathy and control, as well as a deep understanding of the culture of digital platforms.

While this study focused on practitioners operating within a relatively homogeneous cultural and national context, future research should investigate how perceptions and strategic constructions of authenticity vary across cultural settings. Given that platforms such as TikTok or Instagram have global reach but host culturally specific norms, the tension between universal strategy and local authenticity expectations represents an important avenue for further study.

6. Conclusions

The results of the conducted qualitative research allow for the formulation of several important conclusions relating to both the theory and practice of brand communication management in the digital environment. The study showed that authenticity in social media is not a permanent or clearly defined feature-it is the effect of conscious communication activities carried out in conditions of organizational, technological and cultural tensions. The respondents clearly indicated that in large organizational structures, authenticity rarely results from bottom-up, spontaneous expression. On the contrary-it is the result of a compromise between emotional freedom and the requirements of institutional cohesion. In theoretical terms, the research shifts focus from the recipients' perspective-dominant in the literature (e.g. Morhart et al., 2015; Napoli et al., 2014) – to the decision-making logic of the sender, i.e. the teams responsible for communication. It thus brings new cognitive value by presenting authenticity as an operational construct, embedded in image management practices and oriented towards adapting to institutional constraints. It also confirms the validity of relational and contextual approaches (Enli, 2015; Lehman et al., 2019), indicating the importance of the platform as an interpretative framework for the “truthfulness” of the message.

In practical terms, the results suggest that authenticity should be managed as consciously as other elements of brand identity. Organizations should develop internal guidelines on the scope and forms of acceptable spontaneity, as well as develop effective models of cooperation between marketing, PR and legal departments that enable rapid and consistent response in situations requiring an authentic tone. It is also important to differentiate messages depending on the specifics of platform-each requires a different tone, aesthetics and dynamics of the message. At the same time, as the respondents' statement show, selectivity in disclosing information is more important than full transparency-recipients value honesty, but recognize redundancy as a strategy, not authenticity.

The research results provide recommendations for practitioners of brand management and communication in the digital environment. In particular, it is worth noting that:

1. Authenticity requires management, not mere declaration. Organizations should include authenticity as a conscious component of their communication strategy, rather than treating it as a default or intentional characteristic. It is advisable to develop internal procedures and guidelines on the scope and forms of acceptable spontaneity in communication.
2. Authenticity management should consider organizational tensions. This requires developing a model of cooperation between marketing, PR and legal departments that will enable a quick and adequate response in situations requiring an authentic tone without excessively slowing down the decision-making process.
3. Communication must be differentiated by platform. Each social media channel requires a different narrative, tone, and aesthetic, while maintaining consistency in the overall brand identity.
4. Selective transparency has value, not full exposure. A brand doesn't have to reveal everything to be perceived as authentic.

The limitations of this study are its exploratory nature and the small, purposefully selected sample. Participants mainly represented the private sector, and their perspective referred to the realities of the Polish market. The research did not include a systematic analysis of recipients' perceptions, which limits the possibility of assessing the effectiveness of the authenticity strategy from the point of view of communication effectiveness.

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TECHNOLOGY ENTREPRENEURSHIP AS A SOURCE OF MODERN INNOVATIVE SOLUTIONS

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Purpose: The purpose of the present article is to identify and assess the impact of technology entrepreneurship on the creation of product innovation of an improving nature, using the example of the products of a selected enterprise. The example used will be the process of improving a PGN-plus 80 universal gripper. This is an interesting case of improved innovative product in tradition sector of industry which causes many processes more effective and efficient.

Design/methodology/approach: In this article the qualitative method, based on case studies procedure was used. Moreover, the aforementioned challenges of the modern world caused significant realignments in the functioning of enterprises. This applies especially to academic enterprises operating in the advanced technology sector. The effects of these challenges will be shown on the example of enterprises X, Y, and Z from the photonics industry.

Findings: This relatively simple example from this article shows that even unspectacular product or process innovations play a significant role in building potential or actual competitive advantages. At the same time, it can point out the right path that companies should follow.

Research limitations/implications: The article also discusses the issue of the impact of unforeseen events of the past several years (the COVID-19 pandemic and armed conflict in Ukraine) on shaping workers' entrepreneurial attitudes and the potential to generate innovative solutions, not just of a breakthrough character but also incremental innovations leading to the improvement of existing products or processes in the spirit of the philosophy of continuous improvement.

Practical implications: In order to maintain their competitive position in the global market, enterprises must effectively and efficiently manage technological change. The ability to perceive the right time to change is a fundamental problem in managing technological innovation.

Social implications: The events of the last few years have allowed for the creation of new entrepreneurial attitudes among employees of the studied high-tech companies representing the photonics industry.

Originality/value: Understanding the seriousness of the situation, as well as perceiving it not only in terms of threats but also technological opportunities, resulted in a greater level of consolidation of the staff and brought a deeper understanding of the mission and shared values.

Keywords: technology entrepreneurship, innovation, high-technology, innovative products.

Category of the paper: Research paper, Case study.

Introduction

In today's economy, an enterprise that wants to maintain – and especially, improve – its competitive position must implement innovation, especially in the area of technology. This is true not only for radical breakthrough innovation but also, and perhaps primarily, gradual, incremental innovation that leads to improvement of existing products. One of the means of increasing an organization's innovation level is technology entrepreneurship – both on an individual and organizational level. Currently, technology entrepreneurship is increasingly a prerequisite for achieving success in the global market.

The purpose of the present article is to identify and assess the impact of technology entrepreneurship on the creation of product innovation of an improving nature, using the example of the products of a selected enterprise. The example used will be the process of improving a PGN-plus 80 universal gripper. This is an interesting case of improved innovative product in tradition sector of industry which causes many processes more effective and efficient. In this case we can refer to an innovation of an improving nature, which will significantly increase the usability of an old-generation product and provide it with a kind of "second life". Incremental innovations are often underestimated, and yet most of the new solutions introduced in the day-to-day operations of many enterprises are precisely this type of innovation.

The essence and origins of technology entrepreneurship

In the conditions of the technological race and the shortening of product and technology life cycles, technology entrepreneurship is gaining particular importance as one of the key manifestations of entrepreneurship. Technology entrepreneurship is interdisciplinary and multifaceted in character and can be considered both at the level of individual initiatives and innovative undertakings in the organizational dimension.

Technology Entrepreneurship is a phenomenon that still arouses wide interest, both among theoreticians and researchers of management and quality science, as well as managers and practitioners. Even though "Technology entrepreneurship" is a term which has been present in the world literature for over half a century (the first conference on the topic took place in 1970), the number of publications on the subject did not increase significantly until the second decade of the 21st century. The theoretical foundations of the concept appeared in "Technology Entrepreneurship", a special issue of Strategic Management Journal from 2012 (Beckman et al., 2012; Kordel, 2018, pp. 9-10). Attempts to define the concept were also presented by (Bailetti,

2012, pp. 2-25). The subject of technology entrepreneurship was also undertaken in many other papers, including by (Muegge et al., 2012, pp. 5-16; Bailetti et al., 2012; pp. 28-34).

In recent years many publications on the topic have also appeared in Polish. The term "technology entrepreneurship" is given different definitions by Polish authors. According to (Flaszewska, Lachiewicz, 2013; Lachiewicz, Matejun, Walecka et al., 2013, p. 18) "technology entrepreneurship can be understood as a process combining elements of academic and intellectual entrepreneurship with entrepreneurship of commercial and business support organizations and with entrepreneurship of owners, managers and employees implementing new technologies and accompanying innovations in the sense of application and distribution of their effects in the market environment". According to (Grudzewski, Hejduk, 2008, p. 80) "technology entrepreneurship is a prerequisite for company success. It implies the process of new product development, using modern technologies, flexible response to changes taking place on the market, as well as introducing innovations in all areas of the company's operation, as well as its co-operators". According to (Kordel, 2018, p. 37) "the phenomenon of technology entrepreneurship occurs when scientific or engineering development creates a key element of an opportunity, which is later transformed into a new investment. A technological venture, based on the latest engineering knowledge, is a direct result of technology entrepreneurship". Still quoting the above-mentioned author (Kordel, 2015, p. 272) "technology entrepreneurship, by combining social dynamics with the dynamics created by the development of new technologies, gives a new perspective on the development of the economy, especially that part of it which is composed of high technology enterprises and which is used to be called the knowledge-based economy". Technology entrepreneurship should be considered in the broader context of an organization's strategy, especially a company's development strategy. Therefore, measures of efficiency and effectiveness of technology entrepreneurship can be those measures that relate to competitive advantage (share of market, profitability ratios, etc.) (Chyba, 2016, pp. 103-104).

An overview of selected definitions of technology entrepreneurship is presented in Table 1.

Table 1.

Technology entrepreneurship. Overview of selected definitions

Authors	Definition
Ch. Beckman, K. Eisenhardt, S. Kotha, A. Meyer, N. Rajagopalan	Technological entrepreneurship occurs when advances in science or engineering create a key element of an opportunity that then forms the core of a new venture, product or service, enterprise or even an entire industry.
P. Kordel	The central role in the phenomenon of technological entrepreneurship is played by technological opportunity, i.e. an entrepreneurial opportunity based on the development of technology. The process of technological entrepreneurship consists of the stage of formulating a technological opportunity and the stage of its exploitation.
W. Grudzewski, I. Hejduk	Technological entrepreneurship is a prerequisite for the success of an enterprise. It signifies the process of creating new products, using modern technologies, reacting flexibly to changes on the market, as well as introducing innovations in all areas of the company's operation, as well as at its subcontractors.

Cont. table 1.

S. Flaszewska, S. Lachiewicz	The process of ensuring greater practical utility of scientific research results through effective cooperation between research and research and development centers, capital market institutions and the surroundings of business, as well as enterprises involved in the production and sale of technologically advanced products or services.

Source: own development based on Beckman, Eisenhardt, Kotha, Meyer, Rajagopalan, 2015, pp. 271-282; Grudzewski, Hejduk, 2008; Flaszewska, Lachiewicz, 2013, p. 18.

The concept of technology entrepreneurship should be placed in the field of strategic management issues, including innovation theory and entrepreneurship theory. Technology entrepreneurship is most applicable to high-tech industries, although it can also be applied to traditional industries. It is a process consisting of entrepreneurial actions by an innovation leader, team members, and members of the entire organization. It is a special process that is characterized primarily by creative, collaboration-oriented activities or processes, innovation, a willingness to take risks, and a positive orientation on their results, primarily for social benefit.

Technological entrepreneurship is an innovative process that can be considered on two levels. The first is the stage of creating change for innovation and the chances of using it. The second is to implement and commercialize the innovation. Hence, it follows that technological entrepreneurship is also a specific, multi-stage execution, non-routine actions that are often undertaken, as well as a specific definition in the field of project management. It is necessary that technological entrepreneurship be considered in the context of business decisions and the determinants of its formulation.

According to (Kordel, 2015, pp. 271-282) "a central role in the phenomenon of technological entrepreneurship is played by a technological opportunity, i.e. an entrepreneurial opportunity based on the development of technology. The process of technological entrepreneurship consists of the stage of formulating a technological opportunity and the stage of exploiting it". According to (Korpysa, 2023; KUczęba, Jędrzejczyk, Smoląg et al., 2023, pp. 176-177) "technological entrepreneurship as a paradigm of agile entrepreneurship does not have a single, universal definition. In relation to the organization, it should be considered in the broader context of the development strategy".

Technological entrepreneurship levels and determinants

Among the factors influencing the technological entrepreneurship of an organization, it is necessary to distinguish internal determinants, i.e. the conditions of the organization's internal environment (organizational culture, intellectual capital, etc.) as well as the technological potential of the enterprise, including not only its technological portfolio, but also the creativity of its employees, and in particular the effectiveness of R&D activities. Technological potential may, but does not have to, translate into technological entrepreneurship

and market effects of the enterprise. An important role should also be played by institutions from the surroundings of enterprises, which are established to directly or indirectly support the entrepreneurial aspirations of organizations (scientific institutions, including universities, research institutes, R&D units, as well as innovation and entrepreneurship centers, training and consulting centers, etc.). When talking about technological entrepreneurship, the conditions of the internal environment and the environment of the organization should be taken into account. Table 2 presents a summary of the determinants of technological entrepreneurship in a three-level configuration.

Table 2.

Technological entrepreneurship levels and their key determinants

Technological entrepreneurship levels	Key determinants
Environmental (external) determinants	Scientific institutions
	Centers supporting commercial implementation
	Commercial partners
Internal environment conditions	Organizational culture
	Intellectual capital
	Decision-making efficiency
Enterprise's technology potential	Technology portfolio
	R&D effectiveness
	Management's creativity and technology competences

Source: own development based on Chyba, 2015, Chapter 7, pp. 87-96.

Technological entrepreneurship is strongly conditioned by the organization's environment, especially those entities that support the commercialization of new technology solutions. An important role is also played by the internal environment, including the specific characteristics and identity of the organization expressed by the created organizational culture, as well as the intellectual capital of the organization, with particular emphasis on its human capital. Also emphasized should be the importance of the technological potential of the company with its current portfolio (set) of technologies and the possibility of creating technologies thanks to the effectiveness of the R&D department and the creative activity of employees.

Determinants relating to the organization's internal environment play a significant role. Internal factors that determine technological entrepreneurship development include intellectual capital and organizational culture. The soft aspects of management, especially those mentioned above, are significant inputs into an enterprise's strategic resources. At the same time, the competences and resources at the disposal of enterprises are an important component of their technological potential. After all, it is difficult to build the technological potential of the company without the appropriate knowledge of employees, their technological competences, as well as creativity and commitment.

Barriers to the development of technological entrepreneurship can be both institutional and mental in nature. On the one hand, they result from the limitations of the political, legal and economic environment, and on the other hand, they are conditioned culturally and

sociologically. Each country or region has its own specificity of entrepreneurship conditioned by history, culture, religion or finally resulting from local and family traditions. The limited volume of this article does not, in my opinion, allow for a broader development of these issues. However, it should be assumed a priori that such conditions play an important role.

Currently technological entrepreneurship is largely limited by the economic slowdown of the past several years. In such conditions, especially in the context of the idea of sustainable development of enterprises and the entire economy, the criteria for generating and implementing innovations undergo re-evaluation. According to the above idea, all innovations implemented should not only fulfill economic objectives by increasing revenue but also play a social and environmental-protection role. This means that technological entrepreneurship should also lead to the implementation of the goals outlined by the concept of sustainable development of enterprises. In crisis conditions, this is particularly difficult, taking into account the uncertainty and increased risk of business operations. Environment-friendly technologies that also directly support social objectives do not meet the criterion of economic efficiency. In view of the above it can be stated that technological entrepreneurship is significantly dependent on those conditions and new ideas of economic development. Any considerations on technological entrepreneurship should take them into account.

Impact of technological entrepreneurship on developing technology innovation

Technological entrepreneurship as a specific ability to make use of key elements of technological opportunity and recognizing its appearance on the market is very effective in implementing new solutions, both in the enterprise and on the market. This brings us to the key issue of implementing innovations.

Innovation is a concept that still cannot be clearly defined in the form of a precise and at the same time universal economic theory (Chyba, Sieczka, 2023; Wiśniewska, Janasz et al., 2023; Sieczka, 2019). J.A. Schumpeter is considered an early champion of the subject of innovation because he defined five categories of innovation, all of them based on so-called “creative destruction”. They include:

- „development of a new product or introduction of goods with new properties,
- introduction of a new production method not yet tested in practice in a given industry,
- opening up a new market,
- acquiring new sources of raw materials or half-products,
- the reorganization of an industry, e.g. creation or breaking of a monopoly” (Schumpeter, 1960).

Currently, there are many definitions describing innovation, depending on the field of science they concern. Selected definitions are presented in Table 3.

Table 3.

Innovation. Overview of selected definitions

Authors	Definition
Brdulak H., Gołębiowski T., „Wspólna Europa. Innowacyjność w działalności przedsiębiorstw” Wyd. Difin, Warszawa 2003.	Innovation means any idea, behavior or object which is new, i.e. qualitatively different from existing and known forms.
Pomykalski A., „Innowacje”, Wyd. Politechniki Łódzkiej, Łódź 2001.	Innovation is a process that covers all the activities connected with the development of an idea, the creation of an invention and the subsequent implementation of a new (or improved) product, process or service.
Ratajczak Z., „Człowiek w sytuacji innowacyjnej”, Wyd. PWN, Warszawa 1980.	Innovation is a product (idea, method, thing) perceived by the entity acquiring it new, information about which is transmitted through specific means of communication. This entity can be either an individual or a social group
Pietrasiniński Z., „Ogólne i psychologiczne zagadnienia innowacji”, Wyd. PWN, Warszawa 1971.	Innovations are changes intentionally introduced by people or cybernetic systems designed by them, which consist in replacing existing conditions with new ones.
Galanakis K. „Innovation process. Make sense using system thinking”, Technovation, vol. 26, 11/2006, p. 1223.	Innovation is the creation, on the basis of new or existing scientific or technological knowledge, of new products, processes, knowledge or services that constitute a novelty from the point of view of the discoverer, the industrial sector, the national economy or the global economy and achieve significant market success.
OECD/Eurostat, “Zasady gromadzenia i interpretacji danych dotyczących innowacji”, Wyd. Komisja Europejska, Third edition, Warsaw 2008.	Innovation is the introduction of a new or significantly improved product (good or service) to the market or the implementation of a new or significantly improved process, marketing method or organisational method in business practice, the organisation's activities or in relations with the environment.

Source: own development based on Brdulak, Gołębiowski, 2003; Pomykalski, 2001; Ratajczak, 1980; Pietrasiniński Z., 1971; Galanakis, 2006, p. 1223; OECD/Eurostat, 2008.

The above definitions point to the conclusion that the concept of innovation can be considered in the objective approach as an effect or in the functional approach as a transformation. Depending on the authors' approach to the size of changes that concern innovations, some of them consider innovations as small improvements, while for others innovation is associated with a breakthrough discovery (patent).

However, there are several universal characteristic features that indicate an innovative product. First of all, innovations are introduced consciously to alter the current state, the effect of which is a practical means of achieving enterprises' development goals. Innovative improvements may concern processes, products, organization, or management methods. In order to introduce such innovations, appropriate scientific, technical, economic and market knowledge is necessary. Apart from beneficial results introducing innovations is also associated with high risk related to difficult-to-predict market demand, needs and reactions of potential consumers and competitors, as well as the risk related to the costs of carrying out such an operation.

Due to the diverse definitions of the term, there are a number of methods of classifying innovation.

Based on the object of the innovation, they can be divided into four groups:

- Product innovation – new or modified goods or services.
- Process innovation – new or significantly modified production method.
- Organizational innovations – new methods of managing a company or plant, new organization of contacts with the surroundings.
- Marketing innovations – new marketing instruments relating to changes in the creation or design of goods, their packaging, promotion or pricing.

The following categories can be defined based on an innovation's significance:

- Breakthrough innovations – as their name implies, these are fundamental innovations involving the creation of previously unknown products or the use of new processes, organizational and management methods.
- Basic innovations – they possess the most important features of breakthrough innovations, although they have a much lesser impact on changes that occur in the product or the manner of work.
- Incremental innovations – they impact product or process modification gradually.

Process innovations and product innovations are closely related and have an equal impact on an enterprise's results. Classifying them into two separate groups is necessary for a detailed analysis regarding the enterprise's areas and activities. In the first stages of the innovation process, it is product innovation that is the most important because the actual physical and material possibilities of innovation most strongly reflect the effects of the organization. However, when the product has passed the growth, maturity and decline phases, it is process innovations that allow revenues to be maintained at least at a constant level.

An interesting and important phenomenon today is the diffusion of innovations between different industries and economic sectors (Brzeziński, 2001). We can talk about the diffusion of innovations when, after their first application, they lose their local character and find further applications in the organization or outside it (including organizations from the industry or sector, as well as from other industries or sectors, both in the country and at the international level). Brzeziński, defining the diffusion of innovations, states that it is "the process of spreading, popularizing innovations in the company and the economy, occurring when, after the first successful application of a new technical or organizational solution, it is adopted by other enterprises". Such a definition does not refer in any way to the scope of dissemination (in the industry or sector, or outside the industry or sector of first application). The scope of considerations in this chapter does not include the process of diffusion of innovations as such, i.e. in the sense of the dissemination (or rejection) of innovations in the categories of reasoning initiated by E.M. Rogers. Further considerations will be narrowed down to discussing examples and factors influencing the diffusion of innovations across industries and sectors. An attempt will be made to:

- answer the question of what factors limit and promote the dissemination of innovations between sectors and industries,
- illustrate the process of this dissemination with selected examples.

As technologies in different industries develop ever-faster to ensure improved economic outcomes, it becomes necessary to support the dissemination of these modern solutions into other sectors. Factors that may support innovation transfer between industries and sectors are:

- removal of legal barriers,
- removal of organizational barriers,
- institutional securing of transfer of science and technology,
- adoption of a holistic approach to preferred solutions,
- flow of employees between companies from different industries and sectors,
- adoption of an open innovation approach,
- favoring a commercial approach.

A diagram of innovation transfer is presented in Fig. 1 and Fig. 2.

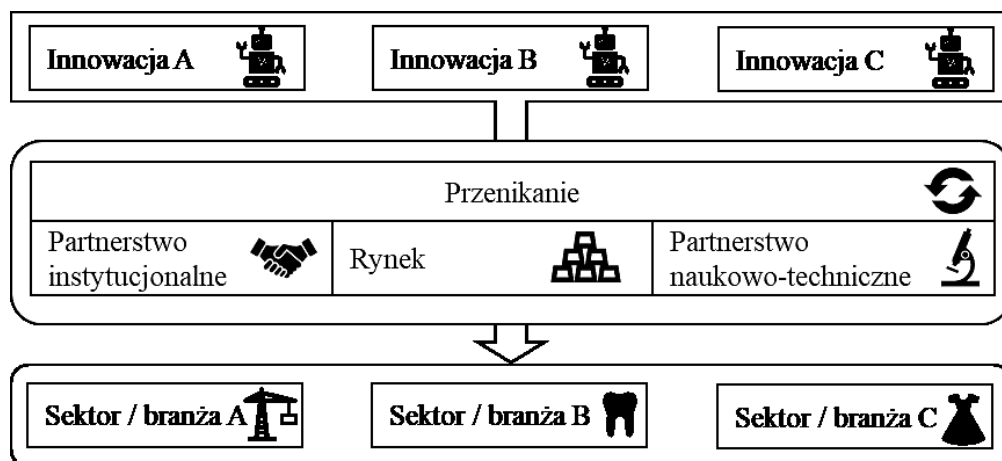


Figure 1. Innovation transfer between industries and sectors.

Source: Marciniak, Gładysz, 2019, p. 23.

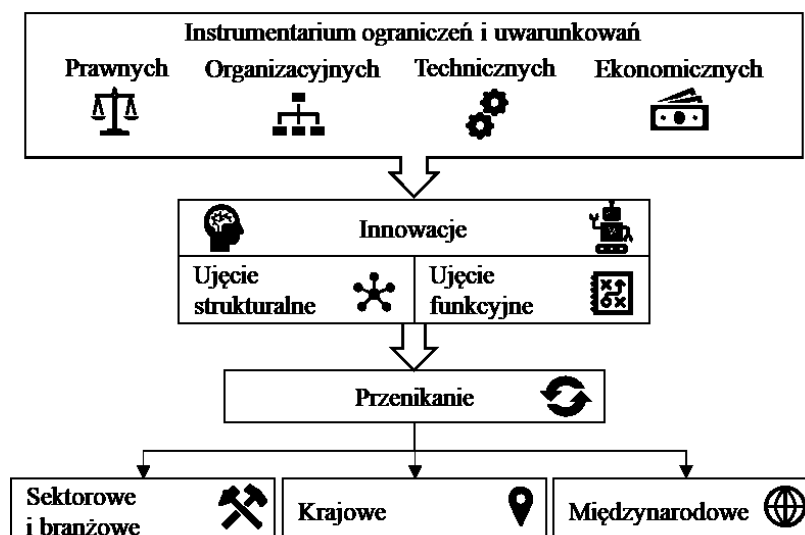


Figure 2. The idea of innovation transfer.

Source: Marciniak, Gładysz, 2019, p. 24.

Innovations can be transferred between sectors and industries in different ways, including through a common market or various types of partnerships (strategic networks and alliances, or scientific and technical partnerships), as well as the flow of knowledge, including that related to employee development or inflow from other organizations. A factor that allows innovations to penetrate between sectors and industries is meeting a need that occurs in various fields of activity. For example, access control systems, which first became popular in the hotel industry, meet the need to supervise access to rooms. And the problem of access control (on a varying scale) occurs in practically every activity. It should be noted that innovations, regardless of their type (process, product, organizational, marketing), can be transferred between different fields of activity when they meet similar needs occurring in different areas.

The fundamental requirement for introducing any product innovation is knowledge (Sieczka, 2019, pp.6-8). Due to the constant changes in the environment, technological progress and the influx of new information every day, this knowledge is an unlimited resource. Operational knowledge is not only an element necessary to introduce product innovation but also its outcome, because implementing a new product allows for obtaining information about the market, the customer can and acquiring new know-how. The ever-changing market requires flexible adaptation of the implementation process. That is why skillful and efficient evaluation of new product implementation is so important. If it is overlooked, an enterprise may fail at a later stage of product implementation, leading to outcomes such as loss of customer trust in its products. This, in turn leads to a decrease in market competitiveness. Figure 3 shows the impact of operational knowledge on an enterprise's success in new product implementation.

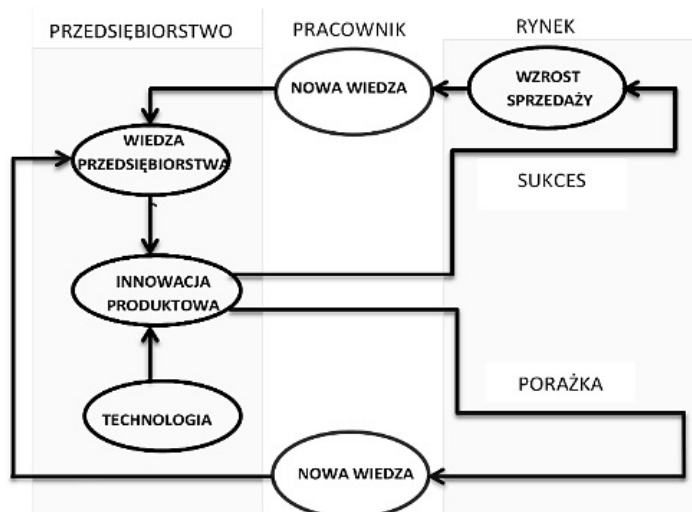


Figure 3. Implementation of innovation as a source of knowledge in the company.

Source: Chyba, Sieczka, 2023, pp. 31-57; Sieczka, 2019, p. 6; Drozd, Kucharska, 2012.

A person as an employee of an enterprise is a key factor in the production system. Skillful management of the human factor, which is the main generator of operational knowledge, has an impact on the company's level of success. Therefore, it is important to properly motivate, reward and invest in such employees. The approach of employees to the company as a partnership, encouraging them to share their knowledge contributes to the creation of innovations (Perechuda, 2005).

The introduction of new products on the market represents expenses of several to more than 10 million zlotys. These costs can concern not only new materials and production equipment but sometimes also the expense of implementing a new technological line. In addition, it is also necessary to take into account listing fees related to building distribution and the cost of promoting a new product. It must be noted that a mature and hence competitive segment involves higher financial outlays. Successful market implementation of a new product requires the efforts of the entire enterprise. This means close cooperation of such functions as production, logistics, marketing and sales.

The literature presents a wide range of product innovation cycle models, differing in the number and names of individual stages. In most cases, the first stages of the models are the stages of generating ideas for a new product and their initial selection. Less frequently, one can find publications that consider the planning stage of the new product creation process as the first one. The product life cycle shows, first of all, that the time a product exists on the market is limited. Each stage of the cycle is characterized by certain opportunities or threats for the product resulting from the market dynamics, which is associated with different levels of financial results. Such different phases require different marketing, production, financial, sales and personnel decisions. The length of the product life cycle depends on micro- and macro-marketing environment factors. The product life cycle also points out that product sales, cost and profit structure are subject to fluctuations and are closely related to the stages of the product

life cycle. Long-term stabilization of the company's profits is ensured by introducing new products and simultaneously withdrawing older ones from the market that are in a declining stage.

The impact of unexpected events on organizations' entrepreneurial behavior and innovativeness

Due to specific conditions of a turbulent environment, today's enterprises are forced to operate under conditions of heightened uncertainty and risk. These exceptional circumstances have intensified especially in recent years due to new unexpected events which were difficult or even impossible to foresee. These unexpected events are frequently referred to as "black swans". These events completely changed the perception of reality not only by enterprises but also by communities almost all over the world. They became game changers. The effects of these events also affected the entrepreneurial behaviors of employees of high-technology enterprises, which perceived these challenges in different ways. In certain cases they reacted with higher worker involvement, stronger identification with the enterprise and an appreciation of management decisions and actions aimed at maintaining jobs. Some high-tech enterprises even saw these unexpected events as a growth opportunity, enabling them to diversify their operations and expand onto new markets.

The aforementioned challenges of the modern world caused significant realignments in the functioning of enterprises. This applies especially to academic enterprises operating in the advanced technology sector. The effects of these challenges will be shown on the example of enterprises X, Y, and Z from the photonics industry (Chyba, Wachnik, Adamiak, 2023, pp. 521-553; Chyba, 2023, pp. 69-93).

Company X was founded in 1987 by a group of scientists from the Military University of Technology. It is an innovation enterprise operating in the high technology sector. It makes use of its own research and development resources. The company's customers are industrial enterprises that manufacture their own products based on its output and the research sector, which constructs scientific equipment. This last group includes enterprises working for the military. Since the company follows a market niche strategy, its sales are conducted through an international distributors' network. Company X is a world leader in the production of uncooled photon infrared detectors. Its mission is to replace cryogenically cooled mid- and far-infrared photon detectors with new generation detectors.

Company Y was established in 1991 by employees of the University of Warsaw Institute of Physics. It is a manufacturer of precision components, optical components and subcomponents for laser technology, medicine, lithography, telecommunications, metrology, aviation and the aviation and space industries. The company specializes in the production of prototypes and

atypical precision elements (Weresa, 2007, pp. 161-165). The company currently holds a high market position, also internationally. It sells its products practically in all the world's continents. It has no Polish competitors and Europe it is able to compete successfully with the best enterprises, manufacturing with a high degree of technological and scientific advancement.

Company Z was founded in 2002 by employees of the Institute of High Pressure Physics of the Polish Academy of Sciences. He specializes in advanced laser manufacturing technologies. Like companies X and Y, it is an example of an entity with roots as an academic spin-off. The enterprise has used and continues to benefit from the help and support of so-called "Business Angels". Due to the niche nature of the business, it has difficulties in obtaining venture capital. The company has very limited possibilities of increasing the scale of production and therefore remains an entity operating in a narrowly specialized global niche. One of the current challenges for Company Z is operating in the field of quantum technologies with a very high level of technology development, which in the future may contribute to the development of so-called quantum computers. The company has a stable team of top-class specialists. It is in the process of hiring new specialists with appropriate experience in research work, preferably with at least a doctoral degree.

On a short-term scale, the occurrence of external uncertainties in the form of COVID-19 forced organizational changes in terms of business processes, procedures, methods of performing tasks and interpersonal relations. These were forced changes aimed at adapting to new conditions mainly in the area of supply chain management, which temporarily partially collapsed, and of the sales process. The period of the pandemic stimulated the enterprise to change the processes of managing its unique and specialized workforce.

Another issue is the entrepreneurial behavior of employees under the impact of unexpected events, known as "black swans". Here we can observe a high level of agreement in the opinions of the employees of all the enterprises. All the organizations experienced an increase in the commitment and creativity of employees, which proves they understood the seriousness of the situation. Representatives of companies X and Z took steps to protect and maintain the numbers of their employees, which the latter appreciated. In the case of company Y, in the period preceding the analyzed events, there were significant personnel changes, which contributed to the increase in technology entrepreneurship of the employees, who undertook numerous creative and innovative activities.

In the case of Company Y, the pandemic and the military threat are perceived less optimistically. Protecting workers in pandemic involved additional costs for the company. According to Company Y's president, "the pandemic crushed the company". Certain supply chains – mostly those from the German market – were disrupted. Regarding the armed conflict, the situation is perceived as more of an opportunity due to the company's cooperation with the defense industry. The company sees another opportunity in the flight of competing organizations from Russia and the possibility of expanding the company's operations in Ukraine. The short-term conditions mentioned (COVID, armed conflict) have prompted the

company's employees to integrate more, consolidate activities and mobilize and motivate the team more strongly. The processes of integrating employees from the organization have intensified and understanding of the company's mission and strategic goals has deepened. The company's problem at the moment is the need for greater automation of production processes, which would enable the scale of production to be increased due to the growing demand and favorable economic situation for the company's products.

In the case of Company Z, the impact of uncertainty in relation to the so-called "Black swans" manifested itself mainly in impeding direct physical contact with potential users of its products, which, by affecting the effectiveness of research and development activities, translated into the functioning of the supply chain and, as a result, diminished the effectiveness and efficiency of market activities. With regard to the armed conflict, in the long term Company Z sees its effects as a development opportunity. This makes Z's way of thinking similar to the previously analyzed companies X and Y. In this case, adopting the strategic perspective may increase the company's sense of uncertainty by limiting access to modern devices that use new methodologies for the use of modern technologies. This concerns primarily the uncertainty resulting from the lack of sufficient information about new devices, as well as the lack of fuller communication between the leading scientific and research centers (Chyba, 2024, pp. 61-70).

In summary it can be stated that the COVID-19 pandemic had a certain impact on interrupting or disrupting supply chains at high-tech enterprises. On the other hand, the threat of international armed conflict caused by the Russian Federation's invasion of Ukraine has caused the outflow of many competing companies from Russia and Ukraine, which created an opportunity for the companies to develop the newly freed-up markets and, as a consequence, for the expansion of these companies in new markets. The companies' products, which are largely niche in nature, generate increased market demand in the current situation. The development of the arms industry and the increase in expenditures for the modernization and rearmament of the army create additional sales opportunities for products manufactured by photonics industry companies in Poland.

The events of the last few years have allowed for the creation of new entrepreneurial attitudes among employees of the studied high-tech companies representing the photonics industry. Understanding the seriousness of the situation, as well as perceiving it not only in terms of threats but also technological opportunities, resulted in a greater level of consolidation of the staff and brought a deeper understanding of the mission and shared values. The attitudes of employees who, on their own initiative, undertook many actions for the development of the company, often giving up their own benefits, including non-financial ones, were a kind of spontaneous test of ethical and entrepreneurial attitudes from the point of view of the company's management.

Summary

In order to maintain their competitive position in the global market, enterprises must effectively and efficiently manage technological change. The ability to perceive the right time to change is a fundamental problem in managing technological innovation. Scientific and technological developments create a technological opportunity that can be used to make a change. This is the essence of technological entrepreneurship, which enables the introduction of innovations, both product and process-related. This does not only apply to breakthrough or radical innovations, but much more often to those of a gradual nature, improving on existing solutions.

This article presents an example of incremental innovation using the example of improvement of a gripper. The technological entrepreneurship of the enterprise's management and all its employees made it possible to utilize a technological opportunity and implement an innovation consisting of the improvement of an existing product. This allowed the company not only to streamline the production organization process, but also to improve the company's competitive position and the effectiveness of its functioning on the global market.

This relatively simple example shows that even unspectacular product or process innovations play a significant role in building potential or actual competitive advantages. At the same time, it can point out the right path that companies should follow. It is necessary to work in parallel, within the limits of resources and potential, both on breakthrough solutions and on improving existing ones. Such a dual track of technological change management is the most effective way to both survive on the market and, as a consequence, strengthen an organization's competitive position and perpetuate its brand.

The article also discusses the issue of the impact of unforeseen events of the past several years (the COVID-19 pandemic and armed conflict in Ukraine) on shaping workers' entrepreneurial attitudes and the potential to generate innovative solutions, not just of a breakthrough character but also incremental innovations leading to the improvement of existing products or processes in the spirit of the philosophy of continuous improvement. Such events, frequently referred to as "black swans", have had a significant impact on changing the thinking and operating of workers and entire organizations which in turn led to increased entrepreneurship and innovativeness and enabled them to compete more effectively on the global market.

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AI ALGORITHMS IN BUSINESS PROCESS AUTOMATION

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Purpose: The aim of the study is to describe cognitive aspects of intelligent AI algorithms, defined in the context of their evolution, and outline AI functionalities necessary for a given organization to support business process automation. The aim of the research is also to describe process according to the systems analysis method in Graham's approach and the cybernetic systems analysis approach, both of which are elements of organisational preparation for implementing tools enabling business process automation.

Design/methodology/approach: The methodology for defining the factors and the relationship between the factors determining process automation depending on the choice of AI algorithm.

Findings: This paper presents ontological assumptions of business process algorithmization, describes algorithm types and defines new models for managing intelligent algorithms in the development of AI for business process automation.

Research limitations/implications: The limitations of using AI algorithms in process automation include issues with data quality, process complexity, high implementation costs, and difficulties in adapting to changing conditions. Additionally, AI can be problematic due to the lack of decision transparency, dependence on technology, system security, and social resistance.

Practical implications: Depending on the main reason for automating a given process (i.e. repetitive data, actions, or exceptions occurring within the process), one can apply deterministic, organized, or self-programming algorithms.

Originality/value: A matrix of AI functionalities was developed in the context of the rationale for automation vs. the type of algorithm that implements the AI functionalities in automating data flows, activities and the occurrence of exceptions in the business process.

Keywords: algorithms, artificial intelligence, automation, systems analysis, cybernetic approach.

Category of the paper: Conceptual paper.

1. Introduction

The level of business process automation within an organization is determined by the degree of freedom (DOF) in developing algorithms that serve as the basis for programming artificial intelligence (AI) used for process automation. It is assumed that algorithmic intelligence is determined by the method of learning. The less intelligent the algorithm, the more learning it requires, which is primarily based on machine data processing and a machine-to-machine (M2M) interface. Thus, if an algorithm relies solely on machine learning, it deals exclusively with data and solves only structured problems within a single-loop of organizational learning. If it employs cognitive learning, it commonly involves a human-to-machine (H2M) interface and relates primarily to information, solving poorly structured problems by applying a double-loop of organizational learning. If an intelligent algorithm is to manage knowledge and solve unstructured problems, it must use a human-to-human (H2H) interface and develop the organization by applying a triple-loop of organizational learning. The cognitive, ontological, and axiological basis of this process involves defining business processes in the context of using management algorithmization functions (Cieśliński, Chomiak, Dudek, 2025). These functions include:

- problem-solving,
- business process optimization,
- artificial amplification of decision-making processes.

To define the assumptions for the present study, it is necessary to describe the model of DOFs in algorithm development, which constitutes a cognitive-methodological and ontological element of the evolutionary stages of management algorithmization. DOFs in the development of algorithms are determined by their ability to learn. The first degree refers to deterministic algorithms, the second to organized algorithms, and the third to self-programming algorithms (based on Lem, 1976, pp. 3-29; Cieśliński, Jasiński, 2024).

In his works, particularly in “*Summa Technologiae*”, Stanisław Lem has explored two types of evolution: biological and technological. Biological evolution is characterized by continuity, where life, once it emerges, develops through a diversity of species, some of which become extinct while others continue to exist. On the other hand, technological evolution, is a dynamic process in which humans create and refine tools and technologies, gradually blurring the boundaries between what is natural and artificial. Lem, referring to Pierre de Latil's book “*Thinking by Machine*”, presents a classification of effectors, which are systems capable of action. He divides them into three main classes: deterministic, organized, and learning systems (including self-learning systems with the highest degree of freedom). By analogy, we can distinguish three basic types of intelligent algorithms, whose management is based on:

- machine processing – deterministic algorithms, coupled to the environment but without feedback (op.cit),
- cognitive processing – organized algorithms, i.e. systems with feedback (negative or positive), built-in determinism, and operational instructions,
- heuristic processing – self-programming algorithms (capable of self-organization), i.e. recursive systems. These are algorithms capable of self-transformation, with their outputs serving as inputs for future events (Buczek, 2009; Tegmark, 2017).

Based on the assumptions presented above, the following research problem can be defined: to what extent and in what manner does the management of intelligent algorithms, in relation to the AI functionalities necessary for business process automation, facilitate the design, programming, and implementation of an AI-based application for solving business process automation problems? The design of intelligent algorithms supporting the generation of efficient AI functions in business process automation must facilitate the collection, processing, and transfer of information regarding the volume and method of processing data, the number and method of processing actions, as well as the number of exceptions within the process and AI algorithm's approach in handling them (Szajna et al., 2022, pp. 359-360). Therefore, from the perspective of managing algorithms, the goal is to design organizations, organize actions based on these algorithms, improve and refine them, as well as analyze their functionalities (Kisielnicki, 1986, p. 40). Thus, algorithms can be used for: designing, organizing, and improving the development of their own functionalities. In turn, each algorithm can be described verbally, using a step-by-step list, a flowchart, a tree structure, a pseudocode, or in the form of a programming language. In other words, an algorithm written in the form of a programming language is called a program, since that language is understandable to the computer (Buczek, 2009, p. 25). Recursive algorithms, which in our opinion serve the function of intelligent algorithms, play a particularly significant role in managing algorithms. They can serve as a foundation for embedding and encoding their structures in a language understandable to computers. This, in turn, can ultimately be used for developing customized Organization 4.0 or AI Organization. On this basis we can put forward the following hypotheses:

- the higher the level of "intelligence" of the algorithm, and therefore its level of complexity, the greater the effectiveness of streamlining and automating business processes,
- an important factor influencing the effectiveness of AI implementation in business process automation is the degree of freedom (DOF),
- deterministic, organized, and iterative algorithms are good for solving structured problems. To solve unstructured problems, it is necessary to use self-programming, recursive algorithms.

2. Algorithms: toward an intelligent amplifier of business process automation. Current state of knowledge

An algorithm is most commonly defined as a sequence of unambiguous instructions designed to solve a specific problem, producing the desired result for any valid input within a finite amount of time (Prakash, 2016, p. 913). Generally an algorithm can be deterministic, consistently producing the same result for the same input, or stochastic, incorporating randomness into its steps. Conventionally, algorithms are classified into (Cieśliński et al., 2024) (Figure 1):

- sequential, iterative, and recursive - based on the processing method they employ,
- linear (sequence) and nonlinear - based on their progression,
- structured, semi-structured, and unstructured - based on the type of problems they solve (they should use: machine, cognitive, or heuristic processing),
- local, mixed, and non-local algorithms - based on their effect,
- with a single, double, or triple loop of organizational learning - depending on the models of organizational learning applied.

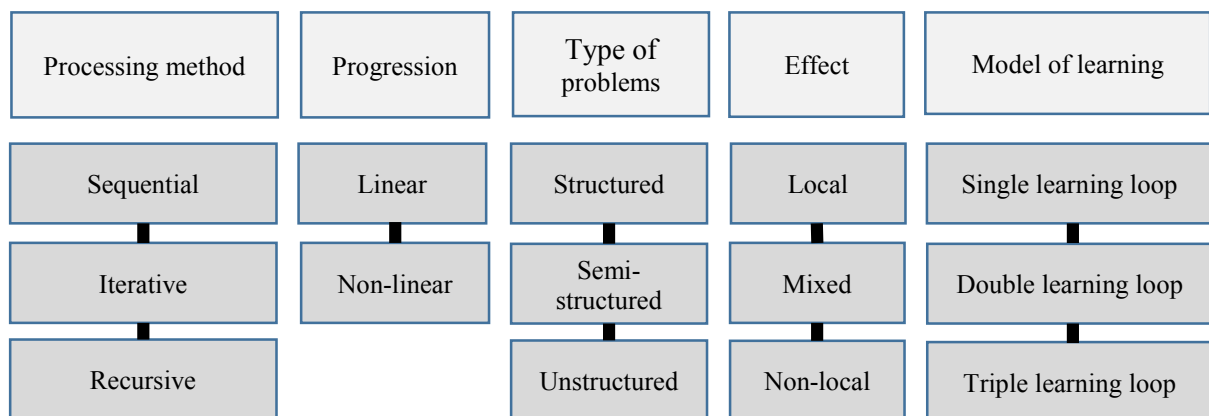


Figure 1. Classification of algorithms according to the adopted assumptions.

Source: Cieśliński et al., 2024.

In turn, an intelligent algorithm is considered a computational method that simulates human thought processes and problem-solving skills to analyze and process complex data. These algorithms most often employ artificial intelligence technologies, including machine learning, deep learning, and data mining (Bouarara, 2017, p. 134).

Based on theoretical descriptions of business models concepts formed by Konieczny (Konieczny, 1986, pp. 33-39) and ourselves using management digitalization and algorithmization (Cieśliński, Chomiak, 2024; Cieśliński, 2024, Cieśliński, Tomanek, 2023; Cieśliński et al., 2023; Hauke, Perechuda, Cieśliński, 2022; Cieśliński, Perechuda, Szewc, 2022; Cieśliński, Chomiak, Dudek, 2025), we propose that AI algorithms used in the management of business process automation and business digitalization must meet several conditions to be applied effectively. We conducted a practical analysis and theoretical synthesis

of how intelligent AI algorithms (Cieśliński, Chomiak-Orsa, Dudek, 2025) fulfill the functions expected by AI users in the context of business processes automation. Our thorough analysis demonstrated that these algorithms should meet specific requirements, including the need for a continuous training process (Cieśliński et al., 2025).

Algorithms are the opposite of heuristics. A machine based on a conventional algorithm will never surpass developmental boundaries that enable learning. An algorithm is equipped with instructions that are strictly determined and unchanging until termination. However, it can use instructions that, through feedback, transform themselves, adapting and learning, into a form different from the initial input (Lem, 1974, p. 123). After a certain number of iterations, the algorithm is instructed to apply free search and operate through trial-and-error, which is a step toward heuristics (Lem, 1974, p. 123).

The machine begins to think, and the amplifier of natural intelligence, i.e. Ashby's machine (Lem, 1974, p. 126), starts operating not according to strict deterministic instructions but based on probabilistic reasoning and intuition, which characterize cognitive algorithms and, most importantly, heuristic algorithms (Cieśliński, Chomiak-Orsa, 2023; Cieśliński, Chomiak-Orsa, Dudek, 2025). Due to the fact that recursive algorithms and their mechanisms are based on future events, i.e. predictions necessary for decision-making (Zieliński, 2000, p. 25), the outputs for a given business process serve as inputs for future events. In other words, if the input data is processed into information and the output is knowledge, a predictive process occurs. Namely, this generated knowledge can initiate the creation and forecasting of future events, enabling the organization to make better decisions, adapting and learning to navigate the new reality. This means that instead of starting with data as initial input, the algorithm starts with knowledge, which is then assigned new meaning by forming predictions. The brain contains structures that computer scientists refer to as recurrent neural networks. Recursion is a method of defining a function that invokes itself to solve a problem. In mathematics and computer science, this is a common technique used to solve complex problems by breaking them down into smaller, more manageable sub-problems. Information flows in multiple directions, allowing the current outputs to become inputs for future events (Tegmark, 2017, p. 105).

In turn, intelligent algorithms are computational methods that simulate human thought processes and problem-solving skills to analyze and process complex data. These algorithms use methods such as machine learning, deep learning, and data mining to extract valuable information and patterns from Big Data, thus supporting decision-making processes (Pu, 2024, p. 2). "Intelligent algorithms" (optimization, evolutionary, heuristic) is a general term referring to methods and procedures that imitate certain aspects of human intelligence. These are usually algorithms designed to solve problems that require an "intelligent" approach. Intelligent algorithm management plays a key role in solving organizational problems (Szpringer, 2020; Jiang, 2024; Li, 2024; Koehler, Sauermann, 2024; Hillebrand, 2025), particularly in the areas of process optimization, forecasting, automation, and decision-making, as these algorithms form a structure based on which they themselves are transformed into AI programs (Buczek,

2009, p. 9). Intelligent algorithms are a crucial component of managing Organization 5.0, forming the foundation for solving various types of problems through machine, cognitive and heuristic processing. These algorithms can be classified in various ways (e.g. sequential-linear, iterative-laminar, and recursive-nonlinear). Each of these types has unique properties and applications in the context of organizational problems, organizational learning strategies, and methods of processing data, information, and knowledge. Thus, algorithms, are "recipes" (Cieśliński, 2020; Cieśliński, Tomanek, 2023), that outline all the steps necessary to: automate tasks, actions, activities, and processes; solve problems based on variables such as goals, conditions, and actions; and optimize decision-making by relying on recursions within a finite number of steps and finite time. However, there is a risk of "looping" of recursive operations, i.e. those calling functions, algorithms, and their own processing results (Buczek, 2009; Bhargava, 2017). Thus, an algorithm is only an algorithm when the input data is unambiguously defined and finite, and the output is a clearly specified final result in the form of meaning (Cieśliński, 2020; Buczek, 2009, p. 6). Recursive algorithms are meant to generate input data based on future events rather than historical ones. This is the essence of managing intelligent, recursive algorithms.

3. Overview of AI algorithms

AI algorithms are a more specific subset of intelligent algorithms. They are designed to create machines capable of performing tasks that normally require human intelligence, such as learning, reasoning, problem-solving, and decision-making (Rojas, 2024, p. 2). These algorithms are a particular group of algorithms designed to mimic human cognitive abilities and intelligence, such as machine learning, reasoning, and pattern recognition. In other words, AI algorithms are a subset of intelligent algorithms, but all AI algorithms are intelligent in the sense that they attempt to mimic the human ability to solve problems (Kurp, 2023, pp. 16-32; Kurp, 2022, pp. 9-27).

AI algorithms are a fundamental component of AI technology, designed to enable machines to perform tasks that typically require human intelligence. These algorithms are autonomous sequences of instructions that guide computational machines through a series of well-defined steps to achieve a specific outcome (Deng, 2017, p. 173). AI algorithms are sets of rules, instructions, or computational procedures that enable computers to make decisions, learn from data, solve problems, and perform tasks that have traditionally required human intelligence. They form the basis for AI systems and define how machines analyze data, identify patterns, and generate responses based on input information. Based on the up-to-date subject literature, specifically a review of AI algorithms, we have identified basic types of these algorithms. However, we would like to emphasize that this classification does not entirely align with what

we describe in this study. Stated otherwise, we present a typology of algorithms used in AI programming that is in line with current knowledge, but which we creatively challenge and reinterpret. AI algorithms are sets of rules and techniques that enable machines to learn, make decisions, predict outcomes, and solve problems. They are applied in nearly every field of life, enhancing efficiency and accuracy, and automating complex tasks.

AI algorithms have the following characteristics:

- learning – data is used to improve performance over time (e.g. through machine learning),
- adaptability – algorithms adjust to changing conditions or input data,
- autonomy – tasks are performed with minimum human involvement,
- optimization – target solutions aim to maximize efficiency or minimize costs.

AI algorithms are predominantly applied in areas such as (Kathpal, 2024; Williams, 2024; Callier, Sandel, 2021; Biglarfadafan, 2024; Wei, 2023; Ng et al., 2021; Jingxuan et al., 2024; Silviu, 2025): process automation, service personalization, Big Data analysis, improvements in security, medicine and healthcare, transportation and logistics, agriculture, entertainment, education, scientific research, and more. Algorithms implemented in AI enable enhanced manufacturing and service efficiency, save time through automation, reduce operational costs, improve precision, and minimize human errors. Addressing the needs of an AI-driven environment relies on the chosen approach to problem-solving, commonly referred to as the model. These approaches include (Sen, 2020; Xie, 2020; Uddin, Mashwani, 2024):

- supervised learning,
- unsupervised learning,
- reinforcement learning,
- deep learning,
- evolutionary and metaheuristic algorithms,
- natural language processing (NLP),
- hybrid algorithms.

AI algorithms strive for greater interpretability, computational efficiency, and applications in sectors demanding a high degree of autonomy and precision, such as medicine, aerospace, and finance. Advancements in such disciplines as federated learning and quantum computing are also opening up new perspectives for AI algorithm application.

4. AI algorithms as tools for business process automation

Based on the research assumptions presented above, we propose that business process automation can primarily involve deterministic algorithms, i.e. those that, through machine processing, allow for relieving employees from tedious, monotonous, and repetitive tasks focused on data. If the actions in a process are repetitive, occur in large quantities and with high frequency, and the process involves not only the management of data but also of complex actions and tasks, organized algorithms should be applied (according to the typology proposed). These are algorithms whose processing mechanism is slower compared to deterministic algorithms, but through feedback (positive or negative) they are able to efficiently process the information necessary to handle thousands of repetitive actions over time and within a specific process. In turn, self-programming algorithms based on heuristic processing can be used in the automation of processes where exceptions cannot be excluded (they are suitable for automation but anticipate the occurrence of exceptional situations). In such cases, the algorithm must adapt to the situation through recursive mechanisms, where the outputs serve as inputs for future states, and the subject of analysis is the knowledge the algorithm has within a given process. The intelligence of the algorithm must be directly proportional to the main subject of automation.

If the subject of automation comprises solely large volumes of data records to be processed, the main functionality of AI expected by the user is quick and flawless processing of large amounts of data by the algorithm through an M2M interface. If the subject of analysis constitutes actions within a process, the algorithm must use feedback in such a way as to optimize these actions. If exceptions occur within the process, the algorithm must be capable of operating through trial and error until it learns through recursions how to respond to changes.

Table 1 presents an AI Functionality Matrix in the context of automation determinants relative to the type of algorithm that implements AI functionalities in automating data and action flow, and in handling exceptions within a business process.

Table 1.
AI Functionality Matrix in Process Automation

Intelligent algorithm/ subject of analysis	Data	Actions	Exceptions
Deterministic	AI sequentially processes a large volume of repetitive data within the process - OPTIMIZATION	AI functionalities based on deterministic machine processing algorithms are inadequate for the complexity of the subject of analysis	AI functionalities are insufficient to handle exceptions within the process - INSUFFICIENCY OF AI FUNCTIONALITIES
Organized	AI based on intelligent algorithms using feedback is too time-consuming for analyzing large volumes of data records	AI iteratively processes a large number of repetitive actions within the process - OPTIMIZATION	AI can loop while handling exceptions

Cont. table 1.

Self-programming	AI based on a self-programming algorithm is redundant - REDUNDANCY OF AI FUNCTIONALITIES	AI based on a self-programming algorithm can be useful when repetitive actions involve the risk of exceptions to the established rules, norms, patterns, and operational models	AI recursively processes knowledge about exceptions occurring during the process that is being automated - OPTIMIZATION

Source: own work.

The matrix describes the relationships between factors determining process automation (the amount of data, the number and frequency of actions performed in the process, or the possibility of exceptions occurring in the process that is being automated) in relation to the type of algorithm. It shows whether AI is based on a deterministic sequential algorithm, an organized iterative algorithm, or a self-programming algorithm – in this context, a recursive algorithm, meaning one where the outputs serve as inputs for future events. Therefore, depending on the main reason for automating a given process (i.e. repetitive data, actions, or exceptions occurring within the process), one can apply deterministic, organized, or self-programming algorithms. The use of an algorithm that is inadequate for the subject of analysis may result in operational redundancy, such as applying complex algorithms to simple tasks, and vice versa, i.e. using overly simple algorithms for complex problems (Cieśliński, Jasiński, 2024). Therefore, the methodology for selecting an algorithm to handle the process that is being automated must take into account two aspects: the subject of automation and the type of algorithm applied for automation (<https://academy.uipath.com/learning-plan>; <https://www.uipath.com>; Sobczak, 2024; <https://www.analitykarchitekt.pl/strategia-ai>).

5. Conclusions

Algorithms with high complexity, based on recursion mechanisms, can be used to program AI for automating processes associated with the occurrence of exceptions. Organized, iterative algorithms can be used to program AI for managing the automation of processes that involve a large number of repetitive actions. Simple, deterministic, sequential algorithms can be used to program AI for automating processes that involve handling large volumes of data. They do not require iteration or recursion; they are simply designed to operate automatically without unnecessary time delays.

The research has shown that the use of different types of algorithms for automating business processes enables enterprises to tailor the level of automation to their individual requirements. Organizations can choose the appropriate type of algorithm based on the nature of the problem. The DOF theory demonstrates how the algorithmic degree of freedom serves as a solution for

harnessing AI capabilities in business processes. The higher the level of intelligence (e.g., self-learning algorithms), the greater the flexibility in solving unstructured problems. Application of intelligent algorithms leads to significant improvements in business process management - increased efficiency, reduced operational costs, and the ability to adapt flexibly to changing circumstances.

The AI functionality matrix proposed by the authors allows for the empirical matching of appropriate algorithms with business process automation requirements, based on factors such as the volume of data, functionalities, and handling exceptions.

The article indicates that the use of artificial intelligence algorithms is associated with several ethical and regulatory challenges. The authors point out problems related to data quality, process complexity and high implementation costs. Particular attention is paid to the issue of transparency of decisions, which may give rise to concerns about "black boxes", i.e. the inability to explain how the algorithms make decisions and the steps they take. Additionally, the article emphasizes the dependence on technology and the problem of system security, especially in the context of using local AI models trained on company data, which indicates potential privacy and security threats related to the use of AI. An important aspect is also social resistance, which may result from employee and user fears of automation, being treated unfairly, being too closely monitored and observed or analyzed, and a lack of understanding of how AI works.

Introducing AI into business processes requires taking these challenges into account - both at the solution design stage and in the implementation process.

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FINANCE MANAGEMENT OF THE JOINT-STOCK COMPANIES FROM AUTOMOTIVE INDUSTRY IN THE ERA OF MILITARY CONFLICT IN UKRAINE

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Purpose: The purpose of this article is to assess the impact of the ongoing military conflict in Ukraine on the financial management of automotive companies listed on both the Polish and European stock exchanges.

Design/methodology/approach: The article will analyze 99 joint-stock companies listed on global stock exchanges in 2020-2025. The main research method will be an econometric model, which will be used to determine in which years the automotive industry grew the most and in which years it did not, and whether companies have faced significant financial problems since the start of Russia's invasion of Ukraine.

Findings: As a result of the econometric model estimation process, it was observed that the analyzed companies from the automotive industry, whose shares are listed on global stock exchanges, grew the most in 2020. In result of research the reported net profit had the greatest impact on the value of these companies. The year 2022 brought the largest financial losses. At the beginning of the war in Ukraine, stock exchanges around the world reacted very negatively.

Research limitations/implications: The research limitations result that the estimated econometric model uses net profit recorded in 2020-2025 (six variables) as independent variables. The dependent variable is the average value of the company from the same research period. In the future, the author would like to expand the research, focusing on estimating more complex econometric models constructed in relation to the development of an AI-based business model.

Practical implications: An article is also aimed not only at scientists, but managers, investors, analysts, regulators and listed companies, too. The study may help in the process of designing more resilient financial strategies for future economic crises.

Social implications: From a social perspective, the content presented in the article may shape public awareness of the impact of armed conflicts not only on geopolitics, but above all on the entire economy, risk of reduced employment in the automotive industry and security, not only economic but also military.

Originality/value: The research conducted for this article provides a broad perspective on the automotive sector, where military and financial issues intersect.

Keywords: military conflict, joint-stock company, net income, enterprise value.

Category of the paper: research paper.

1. Introduction

The armed conflict in Ukraine, which has been going on for almost four years, has completely changed the geopolitical reality, negatively affecting the economies of countries around the world. In this case, one can speak not only of a military crisis, but also of an energy, financial and, above all, economic crisis. In addition, the strong weakening of the zloty to the lowest levels in more than 20 years also affected the decisions of stock market investors. At the time, the Moscow stock exchange suspended operations and markets around the world reacted very nervously. Nevertheless, the stock prices of joint-stock companies involved in the production and sale of raw materials skyrocketed. Over time, the situation normalized. Yet, as is the case in war, some investors lost heavily, while others made money on the discounted shares of non-military companies.

The automotive industry, which the author focuses on in the article, is very prone to crises. Therefore, the purpose of the article is to try to examine the impact of the war in Ukraine on the financial management process of automotive companies listed on global stock exchanges.

Companies operating in this industry depend on global supplies relying, among other things, on the supply of so-called "semiconductors," resulting in changes in raw material prices. This is a crucial situation especially for the European labor market and exports.

Currently, there is already not only a military war, but also a trade war being waged between the US and China. Many car companies are sounding the alarm about shortages of key raw materials, without which there is no chance of maintaining the production of new cars. The Alliance for Automotive Innovation, which brings together major companies from around the world (including General Motors, Hyundai, Toyota, Volkswagen), warns that the problem is growing year by year, predicting that "in just a few weeks, car factories in many regions of the world will stop working or severely reduce production" (T. Okurowski).

The research method used in the article presented here is an econometric model constructed using the classical least squares method incorporating linear regression, where the coefficient of determination R^2 also plays an important role. The article analyzes 99 joint-stock companies listed on global stock exchanges for the years 2020-2025. In the estimated econometric model, the author seeks to study the effect of net profit of each year (years 2020-2025 as independent variables sequentially from x_1 to x_6) on the averaged value of the company (dependent variable y).

The estimation results of the econometric model clearly indicate that Russia's invasion of Ukraine has hit the financial health of listed automotive joint-stock companies very hard. Taking net profit into account, in this respect the analyzed companies recorded the largest growth in 2020. In subsequent years, the media increasingly publicized what is now happening in Ukraine, especially since the armed conflict has been going on practically since 2014. Only until February 2022 was there no escalation on such a large scale as now.

However, despite numerous attempts to carry out analyses of the impact of the war in Ukraine on globalization in the broadest sense, there is still a lack of scientific studies that focus on the financial health of automotive joint-stock companies. Therefore, in the future, the author would like to expand the research, which would consist of the process of estimation of a complex econometric model considering the analysis of business models additionally supported by machine learning algorithms.

2. Literature review

The process of financial management in joint-stock companies and, by extension, the level of financial health involves strategic decisions made by their boards of directors, which specifically concern resource allocation, capital structure and financial risk management (Brigham, Houston, 2019). In contrast, what is happening now prompts entrepreneurs to improve their financial condition to ensure a better life and thus, higher profits, not only now, but also in the future. There are many ways to improve one's financial condition, but first and foremost, this most important way to heal it is through investment, which is generally seen as a sacrifice of present yet certain benefits in favor of those uncertain effects to come in the form of additional financial resources (Anastasia et al., 2023, p. 36).

Armed conflicts around the world bring a lot of evil. Innocent people die, some people lose, others gain, the leaders of the countries are also driven by interests, but not those of ordinary people but political ones. First, as the actress mentioned earlier, they shape the geopolitical and economic situation on a global scale. As in Sudan, Ukraine or other countries, armed conflict affects a country's economy, both macro-economically and micro-economically, through various channels, including imports, exports, production and industry, services (public and private), etc. (Siddig et al., 2023, pp. 1-29; Mahadi Ali Mohamed, Lucero-Prisno, 2025).

Since the article touches on the impact of net profit on the value of a company, it seems important to emphasize the role of the Value Based Management theory, according to which "financial management should focus on maximizing the market value of the company, not just on net profit" (Wielicki, Baum, 2009, p. 239). Thus, Value Based Management (VBM) theory is seen as an element in the overall process of managing a company's finances, which "allows to connect its strategy with its financial performance, including. among others, net profit (Waśniewski, 2011, p. 117). This type of financial management is defined as a set of activities that allow to increase the fixed assets and intangible assets of the company through greater efficiency in the consumption of resources and, most importantly, the competitive advantage of a specific joint stock company listed on the stock exchange (Wielgórka, 2012, pp. 37-38).

Accordingly, value management has become a new way of managing joint stock companies in many parts of the world. In this case, the key role of the value of a business entity in the whole process of business management is emphasized, which is based on improving the overall financial health of the company, "emphasizing the unity of external market value and internal economic value of the company, which is a modern extension and the latest development of business management theory". The effectiveness of the whole process of managing the value of a company, which by virtue of its stock market listing changes in a fairly short period of time, has been confirmed by the successful application of this method in many large international corporations. For example, the company Daimler Chrysler in Germany, whose value and the amount of net profit achieved in 2020-2025 is also analyzed in the article, "has made value management one of the main strategies for the development of enterprises in the 21st century" (Sun, 2023, p. 87; Verma, 2017, pp. 354-382).

Therefore, the value of a company reflects their long-term capacity for sustainable development. And given the analysis of the impact of net profit on the value of a listed company, this article contributes to further enriching the literature review with theories explaining the essence of the economic effects of capital multiplication and profit generation by the business entities under study. Thus, investment in shares by joint-stock companies in the automotive industry contributes to increasing their market value on the other hand, rational allocation of the asset structure of the business entities under study is important for increasing their value (Huang, 2023, p. 594; Jonueviien, 2022, pp. 28-36).

According to some scholars, listed companies are willing to invest more resources in cooperation with other business entities to increase their market value. Besides, companies can gain certain effects in the context of information sharing and knowledge flow (Fu et al., 2016, pp. 59-67). On the one hand, "the sharing of information between business units can contribute to the reallocation and utilization of resources or information in the network, weaken the inhibiting effect of information asymmetry on business efficiency, and promote effective cooperation between businesses and the generation of new knowledge, thereby improving business value" (Mcevely, Marcus, 2005, pp. 1033-1055). On the other hand, "the integration of enterprise resources based on shared resources is conducive to encouraging listed companies to jointly solve difficult problems, improving the efficiency of cooperation and enterprise value" (Vorhies et al., 1999, pp. 1171-1202; Zhang, 2021, p. 3).

In the case of joint-stock companies listed on the world's stock exchanges engaged in the business of car manufacturing, which, as is well known, are characterized by a multitude of products, technologies and processes of various kinds, the supply chain alone is so complex that without cooperation with other business entities, as the author mentioned earlier, it becomes almost impossible to continue operating. Planning for the purchase of materials necessary for the production process of autos and the aforementioned supply chain in such a company primarily involves car dealers and many suppliers, whose embedded process involves thousands of companies supplying products ranging from raw materials such as steel, plastics,

etc. to complex assemblies and components such as transmissions, brakes or finished engines (Sabadka, 2015, p. 15; Manjunatha et al., 2009, pp. 658-667; Yoga Irsyadillah, Dadang, 2020, pp. 12-22).

Therefore, the increased cooperation of the surveyed business entities can contribute to improving their financial condition at a time of continuing armed conflicts ongoing in Ukraine or Gaza. The use of mechanisms for innovative design of the car production process is important for the market success of joint-stock companies in the automotive industry. In addition, the demand for cars produced in accordance with so-called sustainable development is growing exponentially every year (Endler, Andrade Júnior, 2018, p. 31; Arcos-Novillo, Güemes-Castorena, 2017, pp. 1-15). Thus, the importance of the dual transformation of digital and climate and of taking care of environmental sustainability stems from the realities in which we live. At the European level, this type of transformation is carefully planned and monitored. This is since automotive companies, large-scale factories that mass-produce cars, belong to a category of industry that unfortunately contributes to economic growth and at the same time to raising living standards. Through this, it is also responsible for producing a large amount of toxic waste (Istrițeanu, Băjenaru, 2024, p. 101; Masoumi, 2019, pp. 1-30; Luthra et al., 2014, pp. 170-199; Singh, 2024; Darnhall et al., 2008, pp. 30-45).

Analyzing the material gathered in the literature review for the purpose of this article, it should be noted that there is a lack of empirical studies and academic articles in which armed conflict is combined with issues describing the process of managing the finances of companies and, in addition, the finances of joint stock companies in the automotive industry. Most of the available studies focus on the disruptions arising in supply chains or the production process, and not on the disruptions caused by the deteriorating financial condition of these companies because of the outbreak of war in Ukraine and now even in Gaza. Above all, there is a lack of quantitative data to show how companies adjust their capital structure, profits generated, or investments made during the ongoing war.

3. Methods

To illustrate the relationship between the values of the joint-stock companies studied and the net profit recorded by them in 2020-2025, the following section of the article presents an econometric model, the construction of which is based on available empirical data. These data are presented in the following table (Table 1).

Table 1.

Data presenting the financial condition of the 99 joint-stock companies studied in 2020-2025 (data in million)

Lp.	Name of the company	Average value of the company (y)	Net income					
		2020-2025	2020 (x1)	2021 (x2)	2022 (x3)	2023 (x4)	2024 (x5)	2025 (x6)
1.	TESLA	862716.5	721	5,519	12556	14997	7091	6110
2.	TOYOTA	46900329.33	0	2245261	2850110	2451318	4944933	4765086
3.	FERRARI	59720.33333	607.82	830.77	932.61	1252	1522	1582
4.	MERCEDES	161100.3333	3627	23006	14501	14261	10207	8911
5.	BAY	144396.6667	3775	12382	17941	11290	7290	6596
6.	VOLKSWAGEN	257507.6667	8867	15382	15457	16533	11351	9935
7.	HONDA	9875065.667	0	657425	707067	651416	1107174	835837
8.	GM	157397.8333	6427	10019	9934	10127	6008	5812
9.	MARUTI	2377482.5	0	43891	38795	82637	134882	145002
10.	MAHINDRA	2037039.667	0	18125	65773	102815	112686	129291
11.	FORD	169022	-1279	17937	-1981	4347	5879	5018
12.	STELLANTIS	27114.5	2173	14200	16799	18596	5473	0
13.	DAIMLER	37067.66667	-143	2347	2665	3775	2900	2870
14.	HYUNDAI	145223756.3	1424436	4942356	7364364	11961717	12526691	12453039
15.	TATA	2399982.333	0	-134514	-114415	24143	313990	278300
16.	SERES	97255.33333	-1729	-1824	-3832	-2450	5946	6474
17.	LI AUTO	149485.5	-151.66	-321.46	-2012	11704	8032	8090
18.	BAJAJ AUTO	1278536.833	0	48570	61659	60602	77082	73247
19.	SAIC MOTOR	213387.5	20431	24533	16118	14106	1666	1976
20.	SUZUKI	3199005.667	0	146421	160345	221107	267717	416050
21.	KIA	19656505.17	1487585	4760450	5409429	8776970	9772957	9358016
22.	GREAT WALL	224888	5362	6726	8266	7022	12692	11224
23.	GEELY	144314.1667	5534	4847	5260	5308	16632	20744
24.	XPENG	18216.83333	-2732	-4863	-9139	-10376	-5790	-5086
25.	TRATON	29389.16667	-101	457	1141	2451	2804	2518
26.	HYUN. INDIA	218384.1667	0	18812	29016	47093	60600	56402
27.	EICHER	765166.5	0	13469	16766	29139	40010	47344
28.	RIVIAN	24575.66667	-1018	-4688	-6752	-5432	-4747	-3846
29.	TVS MOTOR	687043	0	5943	7568	13287	16864	22356
30.	CHONG QING	61825.66667	3324	3552	7799	11327	7321	7516
31.	RENAULT	55514.66667	-8008	888	-354	2198	752	0
32.	SUBARU	930457.3333	0	76510	70007	200431	385084	338062
33.	SHIMANO	1673505.333	63472	115937	128178	61142	76329	62428
34.	KAWASAKI	1206319.167	0	-19332	21801	53029	25377	88001
35.	HERO	488473	0	29178	23169	28100	37448	43785
36.	ZHEJIANG	25941.5	-1100	-2846	-5109	-4216	-2821	0
37.	ISUZU	1366684	0	42708	126193	151743	176442	134363
38.	NISSAN	6782024.667	0	-448697	215533	221900	426649	-670898
39.	GUANGZHOU	85436.16667	5966	7335	8064	4429	823.58	-1128
40.	VINFAST	9348.833333	-18949885	-35234	-65075	-60168126	-77265364	-80215871
41.	JARDINE	27604.33333	540.3	660.6	739.8	1215	945.8	0
42.	YUTONG BUS	29478.5	515.99	613.79	759.14	1817	4116	4214
43.	YAMAHA	1484546.333	53072	155578	174439	164119	108069	82768
44.	FORD OTOSAN	241023.8333	4195	8801	27730	70826	38864	32959
45.	OSHKOSH	6309.166667	508.9	427.4	173.9	598	681.4	614.2
46.	LUCID	15686.5	-719.38	-2580	-1304	-2828	-2714	-2399
47.	ZEEKR	2467.333333	103.6	-4363	-7934	-8347	-6424	-5160
48.	NIO	28922.66667	-5611	-10572	-14559	-21147	-22658	-24291
49.	IVECO	3673	-408	52	147	218	349	370
50.	BLUEPARK	46789.66667	-6482	-5244	-5465	-5400	-6948	-6886
51.	CHONGQING	28187.83333	58.1	55.64	154.68	24.21	40.02	44.62
52.	VOLVO CAR	92423	5834	12546	15577	13053	15401	13263
53.	YADEA	30945	957.39	1369	2161	2640	1272	0
54.	FAW JIEFANG	12422.5	2672	3900	367.44	806.1	622.43	476.24
55.	ZHEJIANG	17783.16667	364.9	411.52	701.37	1008	1472	1609
56.	MITSUBISHI	461778.6667	0	-312317	74037	168730	154709	40987
57.	AIMA	15707.5	598.52	664	1873	1881	1988	2109
58.	DONGFENG	22007.5	10758	11393	10265	-3887	58	0
59.	MAZDA	561344.8333	0	-31651	81557	142814	207696	114079
60.	LONCIN	10001	479.92	384.8	527.28	583.42	1121	1371
61.	TRIGANO	2343.333333	139.46	222.7	278.4	308.1	374.4	299.7
62.	THULE	36152.33333	1166	1790	1275	1099	1122	1088
63.	MINTH	32722.83333	1396	1497	1501	1903	2319	0
64.	HARLEY	11611.16667	1.3	650.02	741.41	706.59	455.36	353.52

Cont. table 1.

65.	BEIQI FOTON	19301.16667	154.64	-5061	66.76	909.48	80.54	260.06
66.	SINOTRUK	10290	1880	1030	213.72	1080	1480	1516
67.	OLA	34724.16667	0	-1992	-7842	-14721	-15844	-22760
68.	POLESTAR	5067.5	-484.86	-969.3	-479.02	-1182	-2050	0
69.	TOFAS	71486.33333	1784	3281	9374	21777	5221	1206
70.	GT	236450	6546	10983	18360	29313	28783	30812
71.	REV	1349	-30.5	44.4	15.2	45.3	257.6	96.9
72.	CHINA RAIL.	16360.66667	938.11	977.22	709.05	571.09	459.09	475.36
73.	FORCE	77704.16667	0	-1236	-910.8	1336	3881	8007
74.	BAIC MOTOR	18663.66667	2029	3858	4197	3030	955.84	850.33
75.	DONGFENG	9619.833333	553.51	371.75	285.08	200.04	29.16	0
76.	JIANGLING	3477.833333	550.7	574.17	915.05	1476	1537	1361
77.	BRILLIANCE	11997	11.22	11961	7147	7735	3101	0
78.	SANYANG	54831	1938	1830	3116	6298	4770	4608
79.	BRETON	0	0	0	-178.1	-229.41	-274.55	0
80.	LOTUS	1005.666667	0	-110.53	-723.92	-742	-1105	-1030
81.	HANMA	8403.5	-490.59	-1336	-1494	-962.69	157.23	234.7
82.	HINO	514818.6667	0	-7489	-84732	-117664	17087	-217753
83.	ZHEJIANG TA.	3425.833333	211.22	242.72	206.1	280.48	431.26	466.6
84.	GIANT	91588.16667	4949	5930	5844	3401	1264	1112
85.	ATHER	0	0	-2333	-3441	-8645	-10597	-8123
86.	BLUE BIRD	898.8333333	12.19	-0.29	-45.76	23.81	105.55	108.14
87.	YULON	291949.8333	2739	4716	-4697	4691	3955	3524
88.	XIAMEN KING	5188.166667	31.9	-595.22	-386.89	75.1	157.74	186.85
89.	CHINA MOTOR	37684	3277	4182	-7758	5652	4007	3384
90.	DOMETIC	36531.33333	451	1726	1784	1332	-2303	-2395
91.	ASTON MART.	2383.833333	-419.3	-191.6	-528.6	-228.1	-323.5	-264.6
92.	OTOKAR	40419.5	618.27	1042	2018	2841	-3104	-2991
93.	AEROSUN	6554.833333	44.45	66.45	75.71	71.94	-379.03	-374.42
94.	ZHEJIANG QI.	4665.5	239.51	237.61	415.54	464.02	676.74	623.68
95.	OLECTRA	77795.5	0	80.75	353.51	655.95	768.33	1389
96.	MERIDA	60179.5	3993	4650	3389	1692	-699.1	-696.35
97.	JILIN	7190.166667	4929	-449.37	-406.18	-181.27	-718.1	-701.57
98.	NISSAN SH.	61937.33333	0	1917	-2217	3883	407	3033
99.	HONG LEONG	1717.833333	169.32	291.88	210.94	290.61	387.9	467.19

Source: own elaboration based on <https://stockanalysis.com/stocks/industry/apparel-manufacturing/>, 01.06.2025; <https://www.tradingview.com/markets/world-stocks/worlds-largest-autom/>, 20.06.2025.

From the above data, the armed conflict in Ukraine has left a very strong mark on the automotive industry, both regionally and globally. The effects of this are evident in the estimation process of the presented econometric model.

In an econometric model constructed using the classical method of least squares, an important role is played by the coefficient of determination, which informs how much the survey conducts explains what the author wants to measure. The estimated model is described by the following equation:

$$Y_t = \alpha_0 + \alpha_1 x_{1t} + \alpha_2 x_{2t} + \alpha_3 x_{3t} + \alpha_4 x_{4t} + \alpha_5 x_{5t} + \alpha_6 x_{6t} + \varepsilon_t \Rightarrow \alpha_0 + \alpha_1 x_{1t} + \alpha_3 x_{3t} + \alpha_4 x_{4t} + \alpha_5 x_{5t} + \alpha_6 x_{6t} + \varepsilon_t \quad (1)$$

where:

numbers: n - number of units under study,

j - number of explanatory variables,

x_t , α_0 , α_1 , ..., α_j - parameters of the model,

$\varepsilon(t)$ - random component.

Based on the literature review and the research gaps analyzed, research hypotheses were formulated that can answer the question of how automobile companies, especially those whose shares are listed on the stock exchange, should deal with crises in an era of continuing armed conflict. The research hypotheses tested refer to value-based management theory, which is usually based on bringing something new to the company (Bolsinger, 2014, p. 357; Buhl et al., 2011, pp. 163-172; vom Brocke et al., 2010, pp. 333-356). This involves, for example, implementing a new process or changes to an existing venture, which significantly contributes to increasing the market value of the business entity. It is based on VBM that variable y was constructed, which is significantly influenced by net profit for the years 2020-2025 (variables x_1 - x_6). They are as follows:

H0: The structure of the estimated econometric model is linear.

H1: The structure of the estimated econometric model is not linear.

H0: The specification of the econometric model is appropriate.

H2: The specification of the econometric model is not appropriate.

H0: Heteroskedasticity is not present.

H3: Heteroskedasticity is present.

H0: The statistical error assumed in the econometric model has a normal distribution.

H4: The statistical error assumed in the econometric model does not have a normal distribution.

H0: No structural break in the econometric model.

H5: There is structural breakdown in the econometric model.

As the author mentioned above, the estimated econometric model initially included six independent variables defined by the net profit recorded in 2020-2025 (x_1 - x_6), which in turn affect the dependent variable y , the value of the company. The data is presented in Table 2.

Table 2.

Model 1: OLS, using observations 1-99. Dependent variable: y

Items	Coefficient	Std. Error	t-ratio	p-value
const	62116.3	227533	0.2730	0.7855
x_1	-112.196	13.3977	-8.374	<0.0001***
x_2	-24.7159	4.49668	-5.496	<0.0001***
x_3	3.36036	7.29631	0.4606	0.6462
x_4	27.8373	4.43584	6.276	<0.0001***
x_5	-7.74379	2.84716	-2.720	0.0078***
x_6	13.0912	2.82785	4.629	<0.0001***
Mean dependent var	2577060			S.D. dependent var 15386879
Sum squared resid	4.39e+14			S.E. of regression 2183732
R-squared	0.981091			Adjusted R-squared 0.979858
F(6, 92)	795.5850			P-value(F) 5.79e-77
Log-likelihood	-1581.903			Akaike criterion 3177.806
Schwarz criterion	3195.972			Hannan-Quinn 3185.156

Source: own elaboration based on table 1.

In the process of further estimation of the econometric model, because of modification of the adopted variables, the independent variable x_2 had to be discarded, which was also written in the above equation describing the structure of the model. The data are presented in the following table (Table 3).

Table 3.

Model 2: OLS, using observations 1-99. Dependent variable: y

Items	Coefficient	Std. Error	t-ratio	p-value
const	63867.6	226535	0.2819	0.7786
x_1	-118.200	3.07746	-38.41	<0.0001***
x_2	-22.7058	1.07702	-21.08	<0.0001***
x_4	29.8138	1.11778	26.67	<0.0001***
x_5	-6.76740	1.89241	-3.576	0.0006***
x_6	12.0885	1.79697	6.727	<0.0001***
Mean dependent var	2577060	S.D. dependent var	15386879	
Sum squared resid	4.40e+14	S.E. of regression	2174462	
R-squared	0.981048	Adjusted R-squared	0.980029	
F(5, 93)	962.8164	P-value(F)	1.97e-78	
Log-likelihood	-1582.017	Akaike criterion	3176.034	
Schwarz criterion	3191.605	Hannan-Quinn	3182.334	

Source: own elaboration based on table 2.

The construction of the econometric model indicated that the variables adopted for construction were correctly selected. In addition, the coefficient of variation was also higher than 10% as was the coefficient of determination R^2 , which is very high at 98%. The p-values for the independent variables x_1 - x_6 , except for the variable x_2 , which was excluded, are very low, indicating that the variables x_1 , x_2 , x_4 and x_6 had the greatest impact on the y variable.

4. Results

Based on the estimation process of the econometric model, the results of the statistical tests performed are presented. These tests were aimed at confirming the impact of the net profit recorded in 2020-2025 on the values of 99 automotive stock companies listed on global exchanges. These are the following results from tests:

1. Non-linearity test (squares)- H_0 : relationship is linear: test statistic: LM = 95.578 with p-value = P (Chi-square (5) > 95.578) = 4.51244e-19.
2. RESET test for specification- H_0 : specification is adequate: test statistic: F (2, 91) = 599.1 with p-value = P (F (2, 91) > 599.1) = 4.13822e-53.
3. White's test for heteroskedasticity- H_0 : heteroskedasticity not present: test statistic: LM = 98.8826 with p-value = P (Chi-square (20) > 98.8826) = 1.99518e-12.
4. White's test for heteroskedasticity (squares only)- H_0 : heteroskedasticity not present: test statistic: LM = 51.792 with p-value = P (Chi-square (10) > 51.792) = 1.24689e-07.

5. Breusch-Pagan test for heteroskedasticity-H0: heteroskedasticity not present: test statistic: $LM = 25.2346$ with $p\text{-value} = P(\text{Chi-square}(5) > 25.2346) = 0.000125527$.
6. Breusch-Pagan test for heteroskedasticity (robust variant)-H0: heteroskedasticity not present: test statistic: $LM = 3.55336$ with $p\text{-value} = P(\text{Chi-square}(5) > 3.55336) = 0.61533$.
7. Test for normality of residual-H0: error is normally distributed: test statistic: $\text{Chi-square}(2) = 175.935$ with $p\text{-value} = 6.25473e-39$.
8. Chow test for structural break at observation 50-H0: no structural break: test statistic: $F(6, 87) = 12.503$ with $p\text{-value} = P(F(6, 87) > 12.503) = 4.09505e-10$.

The results from the tests indicate that the estimated econometric model is not linear. Its specification is not appropriate. White's test confirms that heteroskedasticity in the model is present. However, Breusch-Pagan test confirms that heteroskedasticity is not present. Nevertheless, the statistical error does not have a normal distribution and at the same time there is a structural break.

5. Discussion

Estimation of the econometric model showed that it is not an ideal econometric model at least because the independent variables adopted are still the same net profit only recorded in each year, which may weaken the parameters and assumptions made. Despite the estimation carried out, it is important to highlight several important limitations because of its construction:

- the autocorrelation of the independent variables was since the use of net income from different years as independent variables may have led to it, which violates one of the basic assumptions of the classical linear regression model,
- the lack of structural variability only reinforced the belief that the model did not consider potential structural changes resulting from the impact of the armed conflict vs. the financial condition of the automotive companies under study, which may have distorted the interpretation of the parameters,
- limited number of observations covering 99 companies. Analysis based on annual data may be insufficient to capture dynamic changes in financial management under crisis conditions,
- the omission of contextual variables such as inflation, fluctuating exchange rates, inflation-changing commodity prices and even fiscal policy, which could have had a significant impact on companies' financial performance negatively affected the overall structure of the model.

All of this may have negatively affected the final shape of the model. Nevertheless, the satisfactory level of the coefficient of determination R^2 as much as possible speaks in favor of what the author tried to prove by constructing this econometric model.

6. Conclusions

The presented results of the study confirmed unequivocally that the year 2022, especially the moment when Russia's invasion of Ukraine began, was characterized by quite serious consequences that the automotive joint-stock companies suffered as a result, recording losses. Estimation of the econometric model showed that despite the noticeable downward trends in financial performance, the model does not fully capture the complexity of the analyzed phenomenon. Well, based on the research carried out, only one hypothesis was positively verified, according to which the Breusch-Pagan test confirms that heteroskedasticity does not occur (in other cases the opposite was true).

The presence of high correlations between certain variables, especially the correlation between variable y and variable x_3 (net profit in 2022), may have affected the stability of the regression coefficient estimates, thus making it difficult to clearly interpret the impact of individual predictors on the values of individual joint-stock companies. The model did not consider all possible factors influencing the dependent variable, which increased the risk of variable omission error.

In the literature review, not all the theoretical concepts presented were directly reflected in the construction of the empirical model. The theory of 'Value-Based Management' served mainly as a contextual framework for formulating research hypotheses.

Nevertheless, it is difficult to describe with an econometric model what is happening now in the context of spreading armed conflicts. This is supported by the fact that the construction of the model is not perfect, as is the choice of variables. Although the coefficient of determination R^2 reached a very high value (98%).

Future research should consider the following steps:

- using panel data models (e.g., fixed effects, random effects) to account for differences between companies and variability over time,
- introducing macroeconomic and even geopolitical variables into the model as additional predictors,
- conducting diagnostic tests (e.g., the Durbin-Watson test) to assess the quality of the model and meet classical assumptions,
- striving for a stronger link between theory and empirical analysis, so that the conceptual framework not only explains the context of the problem, but also guides the choice of research tools and the interpretation of results.

Given the practical significance of the research conducted, it is worth noting that potential managers in charge of large automotive companies will be able to better understand how the armed conflict has affected the financial performance of companies, and what actions they should take (e.g., more prudent cash management, etc.). As for researchers, the article aims to fill the existing gap in literature, thus showing that it is worthwhile studying the finances of companies not only in stable, but also in very complex, even crisis conditions.

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PROFITABILITY OF HOTEL ENTERPRISES OF THE VISEGRAD GROUP (V4) COUNTRIES IN THE CONTEXT OF THE WAR IN UKRAINE

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Purpose: The main aim of the article is determine the impact of selected economic and non-economic factors on the profitability of hotel enterprises in the V4 Group countries.

Design/methodology/approach: Hypothesis verification procedures based on the non-parametric Kruskal-Wallis test and panel data regression models were selected from among the available research methods. The study adopted the dependent variable defined by net return on assets and used data for 697 hotel enterprises. The research sample includes annual economic data for the years 2019-2023.

Findings: The analysis has showed that the economic variables affecting profitability are GDP and the inflation rate. These variables behaved as expected, namely the research confirmed the positive impact of economic growth and the negative impact of high inflation in the economy. In turn, among non-economic factors, the significant variables turned out to be the variable regarding the occurrence of the SARS-CoV-2 coronavirus pandemic, which was also in line with expectations, while it is worth noting that the invasion of Ukraine by the Russian Federation had a positive impact on hotel enterprises in the V4 Group countries.

Research limitations: The results achieved in the work can be treated as an incentive for further action, in a much broader scope. However, the limitations of the study should be taken into consideration, such as the size of the sample resulting from the annual and complete financial statements only and the adopted research methodology.

Practical and social implications: This research deepen the knowledge of hotel decision-makers on how to identify key factors influencing hotel profitability or understand non-financial factors that can increase the resilience of companies to shocks such as a pandemic or a war in the region.

Originality: Many hotels in the V4 Group countries, after the outbreak of the war in February 2022, have been rented by governments, local governments and international organizations for the purpose of temporary accommodation of refugees. The adaptation hotels to the challenges of migration due to the war has shown the importance of flexibility and the ability of companies to quickly attract external resources to support new customer segments in crisis conditions.

Keywords: Visegrad Group (V4), profitability, hotels, economic and non-economic determinants, war in Ukraine.

Category of the paper: Research paper.

1. Introduction

Cooperation between Poland, Czechoslovakia (since 1 January 1993 the Czech Republic and Slovakia) and Hungary was formally established by a declaration signed on February 15, 1991 – at the Hungarian castle in Visegrad – by two presidents Lech Wałęsa (Poland) and Václav Havel (Czechoslovakia) as well as Prime Minister József Antall (Hungary). Initially, it was a cooperation within the so-called Visegrad Triangle, and since 1993 – Visegrad Group (V4) (Kubin, 2014; Kuźnar, 2017; Krzymowski, 2021). In 2004, Poland, the Czech Republic, Slovakia and Hungary joined the European Union (Fischer, 2018; Bieszk-Stolorz, Dmytrów, 2020), and since 2007 all four countries have been part of the Schengen area.

The V4 Group includes the International Visegrad Fund, which was established in June 2000 on the basis of a joint decision of the Prime Ministers of the Czech Republic, Polish, Slovakia and Hungary. The purpose of this fund is to promote and encourage closer cooperation between the V4 countries by financially supporting joint projects (including in the field of tourism promotion). Cooperation in the field of tourism was initiated on 4 April 2002 in Visegrad by the Hungarian side and is continuous. Every year, meetings are held between ministers responsible for tourism and the presidents of national tourism organisations from the Czech Republic, Poland, Slovakia and Hungary. The effects of the cooperation to date include, m.in, the creation of the Discover Central Europe web portal, the preparation of promotional materials, joint participation and exhibitions at tourism fairs, as well as the preparation of joint tourist products that are promoted in third countries (Żemła, Ziółkowska-Weiss, 2017).

The location of the V4 countries contributed to the development of both multiculturalism and the unique cultural heritage of this region (Tracz, Bajgier-Kowalska, 2020). In 2023, a total of 50 objects from the V4 countries were included in the UNESCO World Heritage List. Cultural objects dominate among them. Poland and the Czech Republic have the most objects entered in the above list (17 each), followed by Hungary and Slovakia (8 each). The most valuable cultural heritage is possessed by cities inscribed in the UNESCO World Heritage List, i.e.: Cracow (1978), Warsaw (1980), Budapest (1987) and Prague (1992). This advantage undoubtedly attracts tourists on the one hand, and on the other contributes to the development of accommodation and recreational infrastructure (Tracz, Bajgier-Kowalska, 2020).

The V4 countries, thanks to the development of tourist infrastructure, are constantly increasing their attractiveness and competitiveness on the international market (Zemanová, 2022). It is extremely important for the Czech Republic, Poland, Slovakia and Hungary to improve the quality of services provided (Dzurov Vargová et al., 2024). The history, culture and geographical location of the V4 countries allow them to cooperate and create both joint offers and tourism strategies (Antošová et al., 2020). When assessing tourism in the V4 countries, it is also important to remember about the very significant one-day cross-border and transit traffic. Despite the fact that these trips take place under the auspices of "invisible

tourism", they also generate expenditures that have a significant impact on the national economies of the V4 countries (m.in. retail, health and fuel) (Michalkó et al., 2021).

Various forms of tourism are developing in the V4 countries. These include cultural tourism (e.g. von Rohrscheidt, 2010; Botlík, Zedková, 2015; Kwiatek-Soltys, Bajgier-Kowalska, 2019; Krogmann et al., 2021; Csurgó, Smith, 2022), as well as urban tourism, which has been gaining importance in recent years (Tracz, Bajgier-Kowalska, 2019; Tracz, Bajgier-Kowalska, 2020).

Tourist attractions, as well as the opportunity to practise various forms of tourism, are conducive to the influx of tourists, who in turn often use accommodation services. However, it is worth noting that in the last few years the hotel industry in the V4 countries has first struggled with the SARS-CoV-2 coronavirus pandemic, which, as a matter of fact, has affected this industry worldwide (e.g. Hao et al., 2020; Japutra, Situmorang, 2021; Sahoo et al., 2021; Ntambu, Loang, 2022; Shah et al., 2022; Komodromos et al., 2022; dos Santos et al., 2023; Kanamura, 2023), and then with armed conflict just beyond the eastern border (e.g. Balli et al., 2022; Pandey, Kumar, 2023; Martins et al., 2023; Okhrimenko et al., 2024). Another problem has been record-high inflation. For example, hoteliers have been wrestling with energy price increases. The pressure of inflation and increased operating costs of hotels forced the industry to increase prices of its services.

The main objective of the article has been the determination of the impact of economic factors and non-economic variables on shaping the profitability of hotel enterprises in the V4 Group countries. The fact of there being hardly any theoretical considerations and empirical research has been one of the reasons for dedicating this study to the issue. There are relatively few studies in the area of hotel enterprises of the V4 Group and the cognitive results presented in them are often inconsistent with each other. However, the view seems to prevail among the authors that macroeconomic factors constitute a significant element shaping the profitability of enterprises, and further research in this area is important both for the development of theory and practice. The originality of the conducted research results from the inclusion of the outbreak of war in Ukraine among the factors that may affect the profitability of hotels in the V4 Group countries.

The research sample consisted of hotels located on the territory of the V4 Group countries, which provided annual financial statements for the years 2019-2023. Demonstration of such relationships required the use of appropriate econometric methods, leading to quantification of the relationship between the variables studied. Among the available research methods, hypothesis verification procedures based on the Kruskal-Wallis non-parametric test and panel data regression models were selected.

2. Theoretical background

2.1. Hotels and similar accommodation in V4 Group

The name "hotel" in each of the V4 Groups has a completely different definition. In addition, official statistics on the activities of hotels in each of these countries are collected in a different way. Therefore, for the purposes of analysing the activities of these facilities in the countries forming the V4 Group, the Eurostat database was used.

The basis was the statistical classification of economic activity of the European Union (with the indicator of "Hotels and similar accommodation" covering hotels, resort hotels, suite/apartment hotels and motels). Based on the data from Table 1, it can be concluded that in 2019-2023, the Czech Republic had the largest number of hotels and similar accommodation facilities, among the countries belonging to the V4 Group. Poland was ranked just behind it. However, it is noteworthy that in 2019 and 2023 (despite the smaller number of hotels and similar accommodation facilities), Polish facilities had more bed places than the Czech Republic. It is also interesting that the Czech Republic – in each of the periods included in the table – had the largest number of four- and five-star hotels compared to Poland, which is almost four times larger than the Czech Republic: 2019 – 770, 2020 – 887, 2021 – 878, 2022 – 908, 2023 – 917 (Statistical Yearbook of the Czech Republic 2020-2024). While in Poland, in 2019-2023, the number of four- and five-star hotels was as follows: 2019 – 494, 2020 – 484, 2021 – 504, 2022 – 536 and in 2023 – 555 (GUS, 2020-2024).

In the Czech Republic and Hungary, taking into account the period before the pandemic (2019), overnight stays in hotels and similar accommodation facilities were more often chosen by foreign tourists than domestic ones. In the Czech Republic, in 2019, foreign tourists were provided with 24 457 218 overnight stays (with the number of 17 551 652 overnight stays provided to domestic tourists). There was a smaller difference between accommodation provided to foreign and domestic tourists in Hungary. In 2019, overnight stays in hotels and similar accommodation facilities was provided to 13 413 406 foreign tourists (compared to 12 393 775 overnight stays provided to domestic tourists).

Table 1.
Hotels and similar accommodation in V4 Group in years 2019-2023

Country	Indicator – Hotels and similar accommodation		2019	2020	2021	2022	2023
Czech Republic	Establishments		6 236	–*	7 685	7 531	7 267
	Bedplaces		328 501	–*	382 402	387 488	371 396
	Nights spent at tourist accommodation establishments	Domestic tourists	17 551 652	13 930 547	15 934 810	21 531 121	21 637 261
		Foreign tourists	24 457 218	6 447 016	5 865 645	16 358 447	21 179 474

Cont. table 1.

Poland	Establishments		4 229	—*	3 949	3 974	3 982
	Bedplaces		368 944	—*	372 005	381 104	395 157
	Nights spent at tourist accommodation establishments	Domestic tourists	38 627 488	23 312 879	29 398 187	42 981 852	43 167 397
		Foreign tourists	15 089 651	4 982 403	5 493 585	12 253 375	14 308 132
Slovakia	Establishments		1 731	1 702	1 720	1 714	1 750
	Bedplaces		108 876	106 692	108 101	107 085	107 889
	Nights spent at tourist accommodation establishments	Domestic tourists	7 238 430	4 639 576	4 357 461	6 221 853	6 787 631
		Foreign tourists	4 605 416	1 652 974	1 097 929	2 884 316	3 624 972
Hungary	Establishments		2 324	—*	1 968	2 219	2 204
	Bedplaces		184 090	158 660	160 974	184 744	185 659
	Nights spent at tourist accommodation establishments	Domestic tourists	12 393 775	7 876 805	8 700 510	12 281 299	11 748 086
		Foreign tourists	13 413 406	3 125 743	4 139 082	10 138 239	11 618 352

* no information in Eurostat database.

Source: own study based on Eurostat, 2024a, 2024b.

2.2. Economic and non-economic factors that may affect the profitability of hotel enterprises

In a wide range of factors that affect the value of an enterprise, its profitability is particularly important. According to the results of numerous empirical studies, profitability is one of the key determinants of a company value (Dang et al., 2019), which shows a strong positive correlation with it. As a result, the issue of profitability is one of the central elements in the economic analysis of an enterprise, which is subject to in-depth research in most decisions of both strategic significance and in the course of operating activity.

Profitability reflects the return obtained by an enterprise in a given period in relation to the causative factor. At the same time, due to the fact that one of the most important factors of value creation is an entity's ability to effectively manage assets (Fiksel, 2003), one of the most crucial profitability indicators – illustrating the economic development of an enterprise – is precisely the profitability of assets (Ratajczak, 2016).

The challenge which businesses are facing today is management in the conditions of uncertainty. According to current research, enterprises are significantly exposed to numerous risks related to the unstable business environment both at the level of individual countries and the global economy (Batra, Kalia, 2016). For this reason, the analysis of the environment has penetrated the analytical practice of enterprises and is one of the key elements of strategic controlling (Kochalski, 2016). Consequently, high dynamics in the macroeconomic environment of enterprises constitutes a factor that must be taken into account when analysing profitability.

The international importance of hotel companies is growing in the global economy (Brida et al., 2016). However, the hotel sector is classified as a cyclical industry, highly sensitive to economic conditions, which is due to the fact that these entities have higher fixed expenses (costs incurred by all enterprises regardless of the degree of their production) than variable costs

(costs that increase or decrease as the company produces more or less) (Bodie et al., 2008). The consumption of tourist services is conditioned by many factors that differentiate its level and structure (Alejziak, 2009). Various classifications of these conditions are found in the literature on the subject. The most important are economic, demographic, social, psychological and cultural determinants (Middleton, 1996; Jedlińska, 2006). The group of determinants distinguished on the basis of the economic criterion is mainly characterized by quantitative factors, while the group of non-economic determinants is specified by qualitative factors. Economic variables, among which macro- and microeconomic variables are distinguished, are considered to be the basic determinants of the level and structure of tourist consumption. Bull (2005) sees the sources of economic impact on tourist demand, among others, in the group of economic factors occurring in the area of tourist reception. They affect tourists regardless of where they come from. These are factors related to the tourism product and to, among others, the level of prices, competition on the market, the quality of tourism products or economic regulations in the tourism sector. Panasiuk (2019) distinguishes among macroeconomic factors, among others, economic growth, real income, consumption level, unemployment level, inflation level, trade balance and budget deficit. In turn, among non-macroeconomic factors, factors such as demographic changes, the level of urbanization, the level of education, the number and generic structure of facilities, factors related to crisis phenomena – sudden economic downturns, natural disasters at reception places, terrorist activities, military conflicts, local and supra-local social political crises, ecological disasters or prolonged adverse weather conditions at reception places, epidemics and pandemics (Panasiuk, 2019).

The literature emphasizes that the financial situation of tourism enterprises and thus its study is important in a number of economic areas (Vozarova et al., 2019; Klietk et al., 2020). Therefore, monitoring financial results is thought to be important in the hospitality industry too (Cárdenas-García et al., 2015; Liu, Wu, 2019).

The financial situation of individual entities can be viewed from different perspectives. Richard et al. (2009) found that the results of an organization represent three specific areas of business performance, i.e. financial performance (such as profit, return on assets, return on investment), market performance (such as sales, market share), and return to shareholders (such as total return on equity, economic value added – EVA, and others). The authors emphasize that the financial situation of hotels can be examined using such indicators as: profit, liquidity indicators, profitability, debt (Claver-Cortés et al., 2006; Jagels, 2007; Xiao et al., 2012; Costa, Costa, 2019).

Determinants of the financial situation of hotel companies were examined from different perspectives and in different countries. Tan (2017) stated that the growth of gross domestic product (GDP) positively affects the profitability of the tourism sector. The increase in GDP encourages hotels to undertake new investments, which in turn can improve their future profitability. Alarcón and Maspera (2015) examined differences in the financial structure, size and profitability of hotels located in three main Spanish coastal areas: Costa Brava, Costa

Dorada and Costa del Sol. They found that hotels on Costa del Sol are the largest and most indebted, and therefore have higher interest rates, which negatively affects their profitability. Arikan (2017) analysed hospitality companies from the USA and confirmed the negative impact of company size and financial leverage on profitability, while company age and liquidity showed a positive impact. Menicucci (2018) concluded that the economic crisis strongly and negatively affects the tourism sector. The hotel industry is very sensitive to economic turmoil, as it reduces demand and prices of its services. In turn, Ben Aissa and Goaied (2014) found that terrorist attacks strongly and negatively affected Tunisian tourism. The research also includes a reference to variables related to, among others, the SARS epidemic in China in 2003. Chen (2007) and Chen et al. (2005), who examined the impact of the occurrence of epidemic on the economic situation of hotels in China and Taiwan, respectively. When it comes to the impact of a hotel size on profitability, empirical studies ambiguously explain how the size of a hotel affects its profitability. Big enterprises thanks to economies of scale, achieve a higher level of profitability compared to smaller ones (Tan, 2017). Larger companies also have cheaper access to financing, which positively affects their profitability (Agiomirgianakis et al., 2012). Ben Aissa and Goaied (2014), on the other hand, found that the profitability of hotels is negatively affected by the size of a hotel and the level of debt.

3. Research methodology

Despite high importance of the relationship between changes in macroeconomic factors and the profitability of enterprises, empirical research in this area is scarce, and the results obtained often do not confirm each other. In addition, the spectrum of macroeconomic variables studied so far seems incomplete. In response to the existing research gaps, the aim of the study is to examine the relationship between the selected macroeconomic and non-economic variables and the profitability of V4 Group hotel enterprises. Financial data that are the basis for calculating the profitability of enterprises were obtained from the EMIS (Emerging Markets Information Service) database, and macroeconomic data from the Eurostat database.

The study used data for 697 hotel enterprises (Poland – 216, Czech Republic – 159, Hungary – 136 and Slovakia – 186). The research sample includes annual economic data for the years 2019–2023.

In connection with the analysis of the literature in terms of the impact of various determinants on the activities of hotel enterprises, the main objective of the study is to determine the impact of selected economic and non-economic determinants on the profitability of hotel enterprises in the V4 Group countries.

In connection with the adopted research objective, research hypotheses were put forward:

H1: The profitability of hotel enterprises varies among the V4 Group countries.

H2: There is a relationship between the profitability of a hotel enterprise and economic factors.

H3: There is a relationship between the profitability of a hotel enterprise and non-economic factors such as the SARS-CoV-2 coronavirus pandemic or the outbreak of the war in Ukraine.

In the first stage of the research, variables that may significantly affect the analysed explained variable of the model were specified (Table 2).

Table 2.

Description of the adopted variables

Variable name	Description
$ROA_{i,t}$	Return on assets ratio converted to annual scale
$NET\_DEBT_{i,t}$	Net debt
$l\_REV_{i,t}$	Natural logarithm of total revenue
COU	Qualitative variable assuming the value of 1 for Poland (POL), 2 for the Czech Republic (CZECH), 3 for Slovakia (SLO) and 4 for Hungary (HU)
$YEAR$	Variable indicating the year of observation
$REAL\_GDP$	Gross Domestic Product
$EXCH\_RATE$	Exchange rate of the national currency to USD
CPI	Inflation index
GOV_DEBT	Government debt
$UNEMPL\_RATE$	Unemployment rate
POP	Population
OR	The tourist interest index of the country calculated as the occupancy rate of bed places in a given period
WAR	Qualitative variable assuming the value of 1 if there is a war in Ukraine, 0 otherwise
COV	Qualitative variable assuming the value of 1 if there is a SARS-CoV-2 coronavirus pandemic, 0 otherwise

Source: own study.

Dependent variable $ROA_{i,t}$ means analysed net return on assets. This variable is often used in research because it is an indicator of a company's ability to generate profit (Ben Aissa, Goaid, 2014). Another $NET\_DEBT_{i,t}$ variable means the extent to which assets are financed by debt. Highly indebted companies bear a higher financial risk compared to those with lesser borrowed capital because they have to compensate shareholders for higher profits (Tang, Jang, 2007). An increase in the level of debt will result in an increase in the cost of borrowing (i.e. interest costs) and, in consequence, will result in a decrease in the profitability of hotels (Tan, 2017).

Potential other selected factors that may affect the profitability of hotel enterprises in the V4 Group countries refer in the study to the size of the company determined by sales revenues (logarithmic variable $l\_REV_{i,t}$), inflation rate (CPI), Gross Domestic Product ($REAL\_GDP$), national currency exchange rate to USD ($EXCH\_RATE$), public debt (GOV_DEBT), unemployment rate ($UNEMPL\_RATE$), population (POP) and an indicator of tourist interest in a particular country (OR).

A special group of factors are phenomena related to crisis situations. They are of different character. Their appearance is unpredictable, sudden and short-lived. It has very strong effects on the activities of tourism business entities in a very short period of time, and the time of adjusting and eliminating the effects resulting from the changes can be very long and even lead to the necessity to resign from running a business. Therefore, two independent variables *COV* and *WAR* were adopted, defining the years of the SARS-CoV-2 coronavirus pandemic and the outbreak of the war in Ukraine, respectively.

In the next research step, with the use of the presented independent variables, a panel multiple regression model was constructed. In econometric studies, by combining data in the form of time series with cross-sectional data, a cross-sectional-temporal sample is created. Econometric models estimated on the basis of such data form a group of the so-called decomposition models (*error component regression models*), called panel models (Greene, 2003; Baltagi, 2008; Mátyás, Sevestre, 2008; Andreß et al., 2013). The step regression procedure allowed to extract an initial list of determinants characterized by the highest degree of correlation with the explained variable and the lowest degree of correlation with other explanatory variables (Stanisz, 2007). The data panel for 697 entities in 5 periods, after taking into account outlier observations, allowed to obtain a sample with an observation size of $N = 3485$.

The resulting regression model is presented with the following equation:

$$ROA_{i,t} = \beta_0 + \beta_1 I\_REV_{i,t} + \beta_2 NET\_DEBT_{i,t} + \beta_3 REAL\_GDP + \beta_4 EXCH\_RATE + \beta_5 CPI + \beta_6 GOV\_DEBT + \beta_7 UNEMPL\_RATE + \beta_8 POP + \beta_9 OR + \beta_{10} WAR + \beta_{11} COV + \varepsilon_{it} \quad (1)$$

The construction of one-way error models is based on the assumption that units of study (or groups of units) differ from each other by certain characteristics that, for a given subject, remain constant over time. The linear model of a one-way error can be presented as follows (Muszyńska, 2006; Karabiyik et al., 2019; Eugenio-Martin, Patuelli, 2022):

$$y_{it} = \alpha + X'_{it} \beta + u_{it} \quad (2)$$

$$u_{it} = \mu_{it} + v_{it} \quad (3)$$

where:

i, t – indexes referring to a unit of study and time respectively,

X_{it} – vector of observations on exogenous variables,

α, β – structural parameters of a model,

u_{it} – random component of a model,

μ_{it} – unobservable and not included in the regression equation individual effect¹ specific to a particular unit of study,

v_{it} – the remaining, purely random part of the random component.

¹ as the individual effect may result from a unit's membership in the i -th group, it is also often referred to as the group effect.

The group effects $\mu_{i,t}$ are interpreted as individual characteristics of the study units that are not subject to change over time.

Two-way error models, in turn, take into account the existence of not only group effects, but also time effects. They assume the possibility that at a given moment the same random disturbance occurs in all units of the study. The construction of linear two-way error models is the same for the construction of one-way error models, with only the random component being decomposed into three components (Muszyńska, 2006; Karabiyik et al., 2019; Eugenio-Martin, Patuelli, 2022):

$$u_{it} = \mu_{it} + \lambda_{it} + v_{it} \quad (4)$$

where: λ_{it} – is an unobservable and time-specific effect not included in the regression equation.

The group effects μ_{it} are not subject to change over time, while the time effects λ_{it} remain constant for all study units.

4. Results

In the next step of the study, the descriptive statistics of the variables were analyzed. Table 3 presents descriptive statistics of the tested quantitative variable.

Table 3.

Descriptive statistics of the studied quantitative variables

Variable name	Average	Median	Min.	Max.	Stand. deviat.	Variable coeffic.	Perc. 5%	Perc. 95%
$ROA_{i,t}$	-2.68	1.80	-805.00	98.75	45.69	17.03	-51.97	34.01
$I\_REV_{i,t}$	1.22	1.26	-4.60	5.92	1.14	0.93	-0.40	2.98
$NET\_DEBT_{i,t}$	0.78	-0.00	-8.02	81.00	3.84	4.90	-0.51	4.11
$REAL\_GDP$	1.97	2.28	-5.30	7.12	3.50	1.77	-4.34	6.90
$EXCH\_RATE$	70.17	4.20	0.85	372.59	126.77	1.80	0.85	353.00
CPI	7.264	5.10	1.94	17.60	5.08	0.69	1.94	15.10
GOV_DEBT	53.75	53.00	29.55	78.69	12.33	0.22	36.88	76.22
$UNEMPL\_RATE$	-0.75	-1.56	-14.72	26.96	9.82	13.03	-14.72	15.04
POP	17.36	10.52	5.43	37.97	13.53	0.77	5.43	37.97
OR	42.47	44.20	24.00	59.20	11.21	0.26	24.00	59.20

Source: own study.

Results of the Kruskal-Wallis test for the evaluation of differences in values $ROA_{i,t}$ among the four countries were: test statistics (H): 88.33, p -value < 0.00. The p -value is much smaller than the typical significance level, which means that the differences in values $ROA_{i,t}$ between the countries are statistically significant. Figure 1 shows the distribution $ROA_{i,t}$ by country. We can reject the null hypothesis (no differences in $ROA_{i,t}$ between the countries), which suggests that at least one of the countries differs significantly from the others in terms of the index $ROA_{i,t}$.

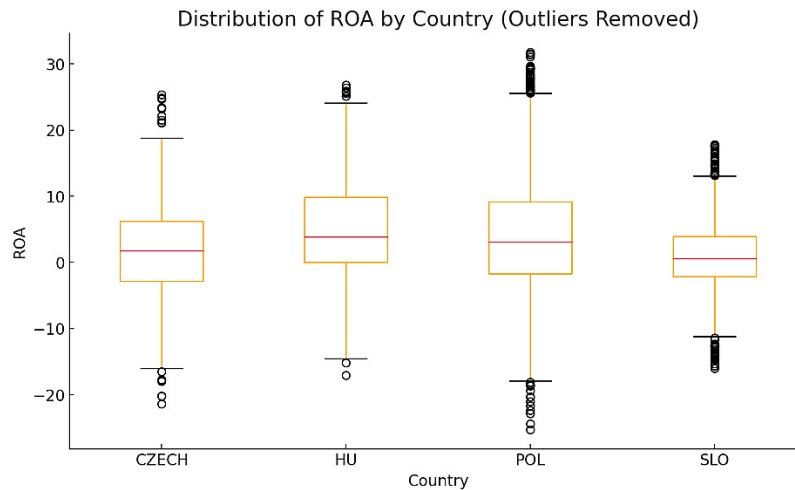


Figure 1. Distribution $ROA_{i,t}$ by country.

Source: own study.

The average level $ROA_{i,t}$ in Poland is characterized by moderate median values. The interquartile range is relatively narrow, which suggests the stability of the index $ROA_{i,t}$ among hotels in Poland. The whiskers are short, indicating that the values $ROA_{i,t}$ are concentrated around a central tendency. The median $ROA_{i,t}$ for the Czech Republic is one of the lowest ones compared to other countries. The interquartile range is noticeable, which indicates a greater dispersion of indicators $ROA_{i,t}$ in this country. Hungary is distinguished by relatively high median values $ROA_{i,t}$, which suggests better profitability of assets compared to other countries. The interquartile range is medium, indicating moderate differences in results $ROA_{i,t}$. Slovakia is distinguished by the highest median values $ROA_{i,t}$, which indicates the best performance of enterprises in terms of asset profitability. The interquartile range is the largest among the analysed countries, which suggests significant differences in the results $ROA_{i,t}$ between the observations.

In next step of the analysis conducted, the correctness of using the least squares estimation method (LQM) was verified (*KMNC*). In the performed diagnostic tests, the Wald test statistic was $F(656, 1908) = 2.22$ with the p -value < 0.00 , which gave grounds to reject the null hypothesis that the *KMNC* panel model is correct, compared to the H_1 hypothesis that the model with permanent effects is more appropriate. Subsequently, the Breusch-Pagan test, where the test statistic was: $LM = 125.13$ with the p -value < 0.00 , means rejecting the null hypothesis that the *KMNC* panel model is correct, compared to the H_1 hypothesis that the model with random effects is more appropriate. Hausmann test statistics: $H = 87.48$ with the p -value $= 0.03$ confirmed the correctness of the use of the model with random effects.

The pooled regression model performed for the aforementioned statistical tests still showed the presence of heteroskedasticity, so that the parameters of the subsequent corrected model introduce robust standard errors. It does not change the values of the estimated parameters, only the error estimates.

First of all, the two-way error model was estimated in the form of:

$$ROA_{i,t} = \beta_0 + \beta_1 l\_REV_{i,t} + \beta_2 NET\_DEBT_{i,t} + \beta_3 REAL\_GDP + \beta_4 EXCH\_RATE + \beta_5 CPI + \beta_6 GOV\_DEBT + \beta_7 UNEMPL\_RATE + \beta_8 POP + \beta_9 OR + \beta_{10} WAR + \beta_{11} COV + u_{it} \quad (5)$$

The results of the estimation of the two-way error model with random effects are presented in Table 4.

Table 4.

Evaluation of parameters of a two-way model with random effects dependent variable $ROA_{i,t}$

Variable	Coefficient	Standard error	t-student	p-value
const	0.769	16.091	0.047	0.96
l_REV _{i,t}	7.878	1.575	5.001	<0.00*
NET_DEBT _{i,t}	-0.489	0.146	-3.339	0.04*
REAL_GDP	1.953	0.491	3.975	<0.00*
EXCH_RATE	0.003	0.015	0.218	0.82
CPI	-1.856	0.494	-3.756	0.00*
GOV_DEBT	-0.096	0.204	-0.471	0.63
UNEMPL_RATE	0.394	0.200	1.961	0.06
POP	-0.39	0.128	-3.062	0.06
OR	0.098	0.237	0.414	0.67
WAR	22.442	4.726	4.748	<0.00*
COV	-12.103	7.824	-1.547	0.04
Between = 380.32 Within = 1192.2 Theta = 0.24 R ² = 0.41				
Breusch-Pagan test: Test statistics: Chi-square (1) = 125.13 with p-value < 0.05 Hausman test: Chi-square (11) statistics = 40.58 with p-value = 0.22 Test for normality of distribution of residues: Test statistics: Chi-square (2) = 186.1 with p-value = 0.06 Residue autocorrelation test: Test statistics: F (1.509) = 8.89 with p-value = 0.06				

*p-value < 0.05

Source: own study.

The results of the analysis indicate factors that statistically significantly affect the dependent variable $ROA_{i,t}$, which among the control variables include the amount of the entity's debt $NET\_DEBT_{i,t}$ (assessment of the parameter $\beta_2 = -0.489$, p -value = 0.04) and the amount of sales revenues (assessment of the parameter $\beta_1 = 7.878$, p -value < 0.00). It is worth noting that the control variables behave as expected.

Among the macroeconomic variables $REAL\_GDP$ has significant effect on the variable $ROA_{i,t}$ (assessment of the parameter $\beta_3 = 1.953$, p -value < 0.00) and the CPI variable (assessment of the parameter $\beta_5 = -1.856$, p -value = 0.00).

On the other hand, non-economic variables, significantly statistical variables were found to be COV (assessment of the parameter $\beta_{11} = -12.103$, p -value = 0.04) and the WAR variable (assessment of the parameter $\beta_{10} = 22.442$, p -value < 0.00).

The estimated panel model accounts for 41% of the impact of selected explanatory variables on $ROA_{i,t}$. Higher intra-group variance (*within*) than inter-group (*between*) in the correct random model indicates that the model better explains the differentiation between individual units over

time than within these units. The results also allow to conclude that unchanged over time unobservable conditions in units, i.e. in the case of a two-way error model taking into account random effects related to a specific unit and time effects, account for 24% of the total random error.

Next, the one-way error model was estimated in the form of:

$$ROA_{i,t} = \beta_0 + \beta_1 l\_REV_{i,t} + \beta_2 NET\_DEBT_{i,t} + \beta_3 REAL\_GDP + \beta_4 EXCH\_RATE + \beta_5 CPI + \beta_6 GOV\_DEBT + \beta_7 UNEMPL\_RATE + \beta_8 POP + \beta_9 OR + \beta_{10} WAR + \beta_{11} COV + \beta_{12} YEAR + u_{it} \quad (6)$$

The results of the estimation of the one-way error model with random effects are presented in Table 5.

Table 5.

Evaluation of parameters of a one-way model with random effects, dependent variable $ROA_{i,t}$

Variable	Coefficient	Standard error	t-student	p-value
const	-2,574.46	3,099.71	-0.830	0.40
l_REV _{i,t}	7.768	1.584	4.904	<0.00*
NET_DEBT _{i,t}	-0.484	0.1463	-3.311	0.00*
REAL GDP	1.856	0.519	3.571	0.00*
EXCH RATE	0.003	0.015	0.248	0.80
CPI	-1.741	0.547	-3.178	0.00*
GOV DEBT	-0.103	0.206	-0.499	0.61
UNEMPL RATE	0.370	0.214	1.726	0.08
POP	-0.374	0.127	-2.929	0.07
OR	0.060	0.239	0.252	0.80
WAR	16.456	9.084	1.811	0.04*
COV	-12.153	7.864	-1.577	0.06
YEAR	1.276	1.536	0.830	0.40
Between = 369.363 Within = 1192.82 Theta = 0.28 R ² = 0.39				
Breusch-Pagan test: Test statistics: Chi-square (1) = 125.11 with p-value < 0.05 Hausman test: Chi-square (12) statistics = 42.25 with p-value = 0.17 Test for normality of distribution of residues: Test statistics: Chi-square (2) = 1809 with p-value = 0.06 Residue autocorrelation test: Test statistics: F (1, 509) = 8.91 with p-value = 0.07				

*p-value < 0.05.

Source: own study.

The results of the analysis indicate factors that statistically significantly affect the dependent variable $ROA_{i,t}$, which among the control variables include, similarly as in the two-way error model, the amount of the entity's debt $NET\_DEBT_{i,t}$ (assessment of the parameter $\beta_2 = -0.484$, p -value = 0.00) and the amount of sales revenues (assessment of the parameter $\beta_1 = 7.768$, p -value < 0.00). The control variables also behave as expected.

Among the economic variables $REAL\_GDP$ has significant effect on the variable $ROA_{i,t}$ (assessment of the parameter $\beta_3 = 1.856$, p -value < 0.00) and the CPI variable (assessment of the parameter $\beta_5 = -1.741$, p -value = 0.00). On the other hand, among the non-economic

variables, the variable *WAR* proved to be statistically significant in the one-way error model (assessment of the parameter $\beta_{10} = 16.456$, p -value = 0.04).

The estimated panel model accounts for 39% of the impact of selected explanatory variables on the explained variable. Higher intra-group variance (*within*) than inter-group (*between*) in the correct random model indicates that the model better explains the differentiation between individual units over time than within these units. The results also allow to conclude that unchanged over time unobservable conditions in units, i.e. in the case of a two-way error model taking into account random effects related to a specific unit and time effects², account for 28% of the total random error.

The analysis has showed that the economic variables affecting profitability are GDP and the inflation rate. These variables behaved as expected, namely the research confirmed the positive impact of economic growth and the negative impact of high inflation in the economy. In turn, among non-economic factors, the significant variables turned out to be the variable regarding the occurrence of the SARS-CoV-2 coronavirus pandemic, which was also in line with expectations, while it is worth noting that the invasion of Ukraine by the Russian Federation, which began on 24 February 2022, had a positive impact on hotel enterprises in the V4 Group countries.

5. Conclusion

In a market economy, the financial condition of enterprises is one of the main determinants of achieving business goals and building a competitive advantage.

Hospitality companies that exist in the modern market do not operate in a vacuum. They operate in a multifaceted economic environment, in which there are complex operations in terms of economic content. All the more so because the modern environment in which enterprises operate is characterized, on the one hand, by the spontaneity and, on the other hand, by the unpredictability of the phenomena taking place.

The study showed that migration processes have become a key factor in changes in the hotel industry in the Visegrad Group countries. After the outbreak of the war in February 2022, millions of refugees from Ukraine poured into neighbouring countries, mainly Polish, but also the Czech Republic, Slovakia and Hungary. Many hotels have been rented by governments, local governments and international organizations for the purpose of temporary accommodation of refugees. These bookings were often long-term and paid for at near-market rates, which provided hotels with a stable and quick cash flow. Hotels participating in support programs for refugees could count on subsidies or direct refunds from state institutions, which improved their

² Illustrating the effects common to all entities in individual years, i.e. a change in the economic situation.

financial results compared to periods of typically low season. The adaptation of V4 Group countries hotels to the challenges of migration due to the war has also shown the importance of flexibility and the ability of companies to quickly attract external resources to support new customer segments in crisis conditions. The war in Ukraine may have impacted sustainability reporting, posing new challenges for the hotel sector. The armed conflict led to mass migration, which in turn generated additional environmental burdens (e.g., increased energy consumption and waste). Socially, hotels, in response to the humanitarian crisis caused by the war, became involved in helping refugees (primarily by providing shelter). In turn, from a management perspective, the war may impact corporate governance in hotels (particularly in the context of data security and risk management, for example).

The results achieved in the work can be treated as an incentive for further action, in a much broader scope. However, the limitations of the study should be taken into consideration, such as the size of the sample resulting from the annual and complete financial statements only. The interpretation of the results also requires caution due to their sensitivity to the adopted research methodology.

These results have important implications. The research presented in this article can enhance hotel decision-makers' understanding of key factors influencing hotel profitability or the non-financial factors that can increase company resilience to shocks such as a pandemic or a regional war. Actions hotel managers can take include, for example, providing staff training in crisis response and refugee support, as well as adapting hotel offerings to changing demand.

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APPLICATION OF IT SOLUTIONS IN THE LABOUR MARKET TRANSFORMATION PROCESS IN POLAND

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Purpose: The primary aim of the paper is to analyse how information and communication technologies (ICT) are transforming the Polish labour market. It seeks to understand structural employment changes driven by technological advancements, such as automation, digitization, and robotization, and how these trends influence employment patterns, demand for specific skills, and socio-economic policies. A specific focus is placed on theoretical models (e.g., SBTC, RBTC, ALM) within the Polish context.

Design/methodology/approach: This study employs a qualitative-descriptive approach grounded in secondary data analysis and a literature review.

Findings: Key findings include:

- Labour market polarization: a rising demand for high- and low-skilled workers with a decline in medium-skilled jobs.
- IT sector expansion: Significant growth, particularly during the COVID-19 pandemic, due to increased digitization and remote work.
- Regional disparities: Urban centres adapt faster to technological changes, highlighting digital and economic segmentation.
- Mismatch in labour supply and demand: Particularly for mid-skilled occupations prone to automation.
- Need for reskilling and continuous learning: Rapid obsolescence of skills due to technological changes.
- Mixed evidence on routine work devaluation: Some routine manual workers in Poland saw wage increases, contradicting standard RBTC predictions.

Research limitations/implications: Generalizability may be constrained due to its Polish-centric focus. The authors identify a need for future research into longitudinal impacts of automation in post-transition economies and micro-level skill adaptation strategies.

Practical implications: The paper suggests that a proactive, system-wide policy response is needed to mitigate risks and harness technological benefits.

Social implications: The paper encourages social inclusion by bridging the urban-rural digital divide through investment in digital infrastructure and education, recommends support for NEET youth to prevent marginalization, and addresses the ethical and societal consequences of automation.

Originality/value: The paper provides a novel synthesis of international labour market theories and Polish labour dynamics, offering a localized lens on global transformations. It bridges academic theory with policy relevance, offering actionable recommendations for education, employment, and innovation systems. It is particularly valuable for policy designers, educators, economists, and those involved in regional development and ICT integration.

Keywords: Labour market transformation, technological change, ICT in employment.

Category of the paper: Research paper.

Introduction

This article explores the multidimensional impact of information and communication technologies (ICT) on the ongoing transformation of the Polish labour market. It seeks to diagnose and interpret how automation, digitization, robotization, and the rapid development of the IT sector have contributed to changes in employment structures and job polarization. The central objective is to evaluate whether these changes correspond to the dynamics predicted by dominant theoretical frameworks in labour economics—namely Skill-Biased Technological Change (SBTC), Routine-Biased Technological Change (RBTC), and the Autor-Levy-Murnane (ALM) task-based model.

Understanding labour market polarization is vital in shaping education policy, employment strategies, and social inclusion frameworks. As Poland navigates the transition to a knowledge-based economy, this research contributes to identifying the drivers of job displacement and creation, enabling more effective labour market interventions and regional development planning.

Research Hypotheses:

1. The Polish labour market exhibits a polarization trend consistent with the RBTC and ALM models.
2. Technological advancement results in the expansion of both high-skill and low-skill employment segments, accompanied by a relative decline in the demand for mid-skilled occupations.
3. The rapid growth of the ICT sector in Poland has contributed to spatial and regional disparities in the pace and nature of labour market adaptation.

Research methodology is based on a mixed-method approach combining a critical review of existing literature with empirical secondary data analysis. Data sources include reports from the OECD, WEF, Polish Central Statistical Office (GUS), and leading academic publications. Task-based classification is applied to interpret wage trends and job displacement across occupational groups. The study also draws on qualitative insights from national case studies and international comparisons.

The study categorizes employment data using the ALM task typology:

- Non-routine cognitive analytical.
- Non-routine cognitive interpersonal.
- Routine cognitive.
- Routine manual.
- Non-routine manual.

Task-based analysis enables disaggregation of wage and employment patterns to examine polarization trends. Employment data from 2010 to 2023 is utilized where available, supplemented with forecasts from OECD and WEF. Additionally, the analysis incorporates demographic variables and regional indicators to contextualize the findings.

Literature review

Theories such as SBTC and RBTC have framed global discourse on technological change and labour market evolution. SBTC focuses on the increasing returns to high-skilled labour, while RBTC emphasizes the vulnerability of routine-based jobs to automation. The ALM framework adds granularity by classifying work tasks into routine/non-routine and cognitive/manual dimensions. Authors such as Acemoglu, Autor, Brynjolfsson, and McAfee have provided empirical evidence of these dynamics in developed economies.

In Poland, the labour market reflects a complex post-socialist evolution, marked by the shift from full employment ideologies to flexible, market-oriented structures. Researchers like Kwiatkowski, Kryńska, Dobija, and Nowak have highlighted key transitions, including the emergence of the NEET generation, the segmentation of labour markets, and the increasing relevance of internal and territorial mobility constraints. Labour economics in this context is enriched by sociological and psychological perspectives, recognizing work not only as economic necessity but also as a form of self-realization and social inclusion.

Structural labour market analyses are conducted for various reasons, primarily due to imbalances between labour demand and supply. Gathering and analysing data on employment levels, internal migrations, and related phenomena enable research beneficial to various institutions such as regional and local employment agencies and companies. Such analyses help identify areas with concentrated human resources and potential profitable locations for investors, such as factories, warehouses, logistics centres, and other facilities. Labour market analyses also significantly impact national logistics planning. Knowledge about migration routes helps manage traffic congestion, facilitating efficient road network expansions and transport infrastructure improvements, which further assist in forecasting migration trends and unemployment levels. Labour market conditions depend on multiple factors, including political

situations, stock market dynamics, economic issues, demographic and social changes, and labour demand-supply imbalances.

Labour economics broadly explores labour-related factors, encompassing economic, sociological, statistical, and psychological aspects. Key topics include wages, employment, employer-employee relationships, and the impact of educational and social changes on labour markets (Dobija, 2016). Kryńska and Kwiatkowski (2013) define the labour market as the space for exchanging labour services between employees and employers, establishing transaction scopes, conditions, and particularly wages. Similar definitions are found in Ehrenberg and Smith's (1991) works. Additionally, Nowak (2011) emphasizes expanding the understanding of "work", acknowledging it not just as unpleasant effort but also skill development, labour utilization, and creativity. However, economic theory traditionally views labour as a difficult effort, a perspective shared by theoretical labour economics and practical human resources management.

Like other markets, labour markets are shaped by supply and demand. Labour supply encompasses all individuals able and willing to work, including both employed and job-seekers offering their services at a given wage. Sapsford and Tzannatos (1993) define labour supply differently, emphasizing "the amount of labour, measured in person-hours, offered for hire at a specific time," noting labour availability depends on workforce supply (Milewski & Kwiatkowski, 2007). Labour market imbalances carry political, economic, and social consequences, observable on two levels (Kwiatkowski, 2002):

1. Excess labour supply over demand leads to unemployment—individuals unable to find employment despite willingness to accept offered conditions.
2. Conversely, labour shortages arise when employers cannot find adequately qualified workers despite offering attractive employment conditions.

Kusideł and Gajdos (2016) highlight that labour demand-supply imbalances significantly impact education systems, requiring dynamic alignment with changing labour market needs and employee expectations. This creates challenges in curriculum selection and necessitates continuous reskilling of academic staff, involving complex cause-and-effect relationships. Labour demand-supply diversity generates relatively closed labour market segments with limited accessibility due to employers' qualifications requirements, artificially created barriers (e.g., excluding unionized workers), and cultural or other obstacles.

According to the Regulation of the Minister of Labour and Social Policy (2014), the term "occupation" is defined as an income source involving tasks derived from social labour divisions, requiring competencies acquired through education or practice, while specialization entails additional competencies. This definition regards workers as specialists producing goods and services. From a sociological perspective, economic aspects highlight the reciprocal relationship between employer and employee, with remuneration reflecting skill levels. While theoretically fair—higher skills yielding higher wages—this approach overlooks time as a factor. Higher-skilled workers receive higher wages but at the cost of additional work and

professional development time. Continuous labour market changes and rising employee demand drive entrepreneurs to adopt flexible employment models to attract talent. Labour market flexibility encompasses employment forms, contract conditions, availability, working hours, remuneration, and work location.

Primary labour market divisions vary according to segmentation criteria. Marshall (1960) initially identified three sub-markets: occupational, local-regional, and industrial. Frequently applied criteria include economic sectors, geographical considerations, required occupational qualifications, and employee types. However, actual labour mobility within these segments is often limited, especially in sectors requiring specific qualifications, regions with restricted mobility, and industries demanding specialized skills (Kryńska, 1995). Internal labour markets relate to organizations employing unified employment and allocation rules, establishing clear criteria for organizational entry and internal advancement opportunities. Market segmentation significantly influences economic convergence, particularly in the primary, high-segment economies concentrated in major urban areas.

Results

The formation of a country's labour market is significantly influenced by its history and culture. In Poland, consequences of a challenging past and pivotal historical events continue to be visible. For approximately 45 years following World War II, Polish economic literature regarded unemployment as a characteristic phenomenon of capitalist economies. During that period, it was believed that unemployment should not occur in socialist systems because labour market policies were based on the principle of full employment. However, similar to other socialist countries, Poland adopted a supply-side approach to the labour market, where employment planning depended on projected workforce supply, adjusting job availability accordingly. Due to inadequate institutional, economic, political, and psychological preparations, Poland was not ready for these changes. Among economic reforms in Poland, changes in ownership structures were crucial, with privatization gradually—albeit minimally—transferring employees from public to private sectors (Orczyk, 2017).

The NEET (Not in Education, Employment, or Training) generation phenomenon is significant in the context of labour market changes, as its consequences may be more severe for society's and economy's future than unemployment alone. Besides unemployment-related costs such as benefits, lost resources, income, and unpaid taxes, Ashton (2007) highlights the increasing economic gap between NEET youth and older generations, arising from growing social marginalization and poverty among these youth. Additionally, Wąsowicz (2016) emphasizes that the NEET generation's situation can negatively affect their long-term career

prospects, including limited employment opportunities and lower wages, which may further adversely affect their physical and mental health.

Globally, increased scope and intensification of human interactions are observed, largely driven by technological advancements. Globalization raises both concerns and hopes from social and economic perspectives. Its interconnected and overlapping aspects complicate assessments, as globalization simultaneously positively and negatively affects development. Consequently, globalization has both proponents, recognizing its benefits, and hyperglobalists, viewing it as a phenomenon capable of fundamentally undermining nation-states' roles (Jurek, 2023). The necessity of implementing flexible employment forms arises from challenges presented by technological progress, increased global competition, and globalization itself. Thus, globalization and technological advancements significantly influence employees' career development (career biographies). Younger generations strive for new experiences and are open to diverse labour market opportunities. Career biographies often become longer and richer, encompassing new employment experiences (Puzio-Waławik, 2016).

Technological progress and globalization undoubtedly impacted the IT sector, where the COVID-19 pandemic exacerbated specialist shortages. Flexible employment models have become preferred primarily due to the nature and execution of most professional tasks. IT professionals are not restricted to local labour markets, frequently able to perform tasks remotely. Rapid globalization and technological changes continuously reshape labour markets, the economy, and society. Current conditions render skills, qualifications, and knowledge quickly obsolete, necessitating continuous learning and improvement. Furthermore, this process encourages creating and utilizing knowledge and information practically, closely linked to the knowledge-based economy.

Labour market polarization is a complex phenomenon significantly impacting both society and individuals in the context of technological changes affecting employment. Consequently, individuals can increase their chances for relatively stable employment, considering rising automation that replaces human workers with machines, equipment, or software. This process gradually eliminates certain types of jobs or occupations susceptible to automation in favor of technological solutions. Labour market polarization became apparent in the early 21st century, visible in employment structures and labour demand. However, Skill-Biased Technological Change (SBTC) theory does not fully explain these shifts. Alongside the persistent trend where technological changes favour highly qualified individuals (increasing demand and wages for highly skilled workers), there simultaneously emerged increased demand for lower-skilled workers, accompanied by wage growth within this group. The group most adversely affected comprises mid-skilled workers, experiencing declining employment demand and wages.

Certain occupations and types of human labour are more readily subject to automation. Tasks that are repetitive, routine, and standardized can be more easily replaced by artificial intelligence, particularly routine tasks described algorithmically or automated through computer programs, machinery, or devices. This phenomenon is discussed within the context

of Routine-Biased Technological Change (RBTC), explained through the Autor-Levy-Murnane (ALM) model. According to this model, worker tasks are classified into five categories based on two criteria: the degree of routineness and the type of activities performed—manual, analytical, or interpersonal (Marinoudi, Pearson, Bochtis, 2019). Acemoglu and Autor's typology of occupational tasks includes the following categories (Acemoglu, Autor, 2011):

- Non-routine cognitive analytical tasks.
- Non-routine cognitive interpersonal tasks.
- Routine cognitive tasks.
- Routine manual tasks.
- Non-routine manual tasks.

Research by Arendt and Grabowski (2019) indicates differences between the Polish labour market and RBTC theory. Their analysis examined the extent to which labour market changes in Poland align with the ALM model and how they result from specific conditions in the Polish economy and labour market. Their primary focus was wage differentiation based on task group affiliations. According to theory, in Poland, significant wage premiums were observed among individuals performing cognitive tasks, especially non-routine cognitive interpersonal tasks. Conversely, RBTC would anticipate declining wages and demand among workers performing routine manual and cognitive tasks. Surprisingly, the researchers found a relative wage increase among Polish workers performing routine manual tasks. Examining technological changes' impact on the labour market highlights the phenomenon of technological unemployment resulting from technological advancement. Consequently, workers have opportunities for skill development and reskilling (Brynjolfsson, McAfee, 2011).

Numerous theories address future labour market transformations, particularly concerning technological advancements, artificial intelligence (AI), and medicine. Technological progress opens new opportunities, with some predictions generating concern, while others appear more optimistic. Nonetheless, all forecasts indicate that technological innovations, automation, robotization, digitization, and artificial intelligence will significantly shape the labour market in the coming years. These factors are expected to diminish occupations requiring only basic skills without specialized knowledge. Besides technological advancements, demographic changes such as an aging population, declining numbers of individuals of working age, migration, urbanization, and labour shortages are also influential.

Research institutions propose various forecasts concerning labour market transformations. According to OECD predictions, 65% of children currently starting school will eventually work in jobs that do not yet exist. OECD experts, in the report "Putting Faces to the Jobs at Risk of Automation", anticipate a stable employment-to-unemployment ratio in the coming years. Nedelkoska and Quintini (2018) indicate that in 31 countries studied, 14% of jobs face high automation risk exceeding 70%. The World Economic Forum (WEF) projects that by 2025, automation might lead to the loss of 85 million jobs globally but simultaneously create 97 million new roles involving new tasks. Consequently, reskilling and career changes will

become essential. WEF experts note that technology implementation will progress steadily, albeit faster in certain sectors. Conversely, Oxford research presents a more daring forecast, predicting complete AI dominance in employment by 2061 and full human replacement by 2136.

While forecasts from institutions like the OECD and WEF provide useful macro-level insights into potential labor market transformations, they are constrained by assumptions of technological linearity, conceptual simplification, and insufficient sensitivity to political, cultural, and ethical dimensions. A more nuanced analysis should integrate qualitative insights, regional case studies, and interdisciplinary approaches to account for the real-world complexity of how technology, work, and society co-evolve.

Institutions specializing in labour market analyses develop forecasts and present their visions of its future. Infuture Institute (2019), in collaboration with Samsung Poland, developed several future scenarios for employees considering various change probabilities. "Jobs are for robots" envisions a future where employment becomes unnecessary, introducing a basic income. Due to rapid technological advancement, automation, and AI, robots will undertake most professional tasks—a scenario already beginning to materialize. The "Hollywood work model" scenario describes work as a passion rather than merely a means to earn income. This scenario anticipates freelancing, turquoise organizations, and flexible employment forms becoming prevalent. Most individuals will independently engage in international projects within virtual reality, overcoming language and geographical barriers, emphasizing work-life balance.

"Always under control" predicts global optimization through constant analysis and enhanced efficiency, precisely assigning employees to tasks and teams. However, this scenario anticipates increased interpersonal tensions and cybercrime resulting from excessive surveillance and monitoring. Privacy would become a luxury, coupled with challenges like overpopulation, growing social inequalities, consumerism, and corporate dominance. "Social workers for planet and nature", one of the most alarming scenarios, assumes that overpopulation, urbanization, environmental degradation, climate change, and lack of potable water will necessitate searching for new living spaces. This scenario emphasizes minimalism, zero waste philosophy, sustainability, and operational transparency.

The Polish Economic Institute (PIE), in the "Foresight of Future Competencies" report, forecasts the impact of virtualization on labour markets by 2035, including distributed teamwork development. The Institute proposes four scenarios: "in the cloud", "smart formula", "offline mode", and "digital detox" (Dębkowska et al., 2022).

The "in the cloud" scenario anticipates advanced labour market virtualization, increasing professional mobility and real-time data accessibility. Effective collaboration within distributed teams will be highly developed. The "smart formula" scenario also foresees virtualization but with lower distributed team capability, highlighting technical, digital, creative, and collaborative skills in human-machine contexts. The "offline mode" scenario predicts low

virtualization and distributed team collaboration levels, potentially reverting to traditional employment forms, reducing occupational mobility, innovation, and international collaboration. The "digital detox" scenario assumes low virtualization but high distributed teamwork capacity, potentially creating a skills gap as highly qualified individuals adjust to traditional working conditions. This scenario emphasizes skills necessary for both stationary and distributed teamwork, focusing particularly on work-life balance.

Labour market transformation occurs rapidly, primarily driven by IT developments and the emergence of new technology-related fields. Kusideł and Antczak (2021) note these processes span all economic sectors. The COVID-19 pandemic notably accelerated labour market transformations, highlighting structural rather than merely quantitative job changes. Generally gradual technological shifts accelerated unexpectedly due to events like the pandemic.

Technological progress continues to critically influence professional life, business, and daily activities. The contemporary world is inconceivable without technology's extensive impacts across various sectors. Technological changes transforming the labour market were accelerated by the pandemic, especially digitization, emphasizing competencies required for non-routine interpersonal and analytical tasks. Although automation often relates to job reductions, it does not invariably lead to employment loss—robots become collaborators, not competitors. Technological transformations generally gradual accelerated due to unexpected events such as COVID-19.

The analysis demonstrates technological development substantially reshapes the labour market, notably increasing demand in the IT sector and elevating the significance of soft and interpersonal skills. Automation, flexible employment forms, and remote work became permanent labour market features. Poland's economy shows quicker adoption of technology-driven employment models in specific sectors.

Secondary data and empirical research confirm labour market polarization, observing increased employment in highly qualified professions and declining significance for medium-skilled occupations. The IT sector exhibits significant growth, accelerated by remote work, digitization, and digital platform development during COVID-19, demonstrating resilience to external shocks.

Analyses also reveal significant regional disparities—developed urban agglomerations adapt faster to technological changes, intensifying territorial segmentation. Studies emphasize the necessity for enhancing digital competencies among high-risk occupations and reforming continuous education systems. Technological shifts redefine employment structures, leading to hybrid models, gig economy growth, and elevated importance of soft and analytical skills.

The contemporary labor market is undergoing a profound transformation shaped by digitization, globalization, and changing social expectations. At the heart of this shift lies the emergence of hybrid job market models, which blend elements of traditional employment with the flexibility and technological underpinnings of the gig economy. This evolving ecosystem challenges long-established notions of work, career trajectories, and professional development,

while simultaneously placing new demands on the skills workers must possess to remain competitive.

The gig economy, often described as a labor market driven by short-term, flexible, and task-based work, is a central component of this transformation. Enabled by digital platforms such as Uber, Fiverr, Upwork, or Glovo, the gig economy reconfigures how labor is organized and compensated. Workers, no longer tethered to a single employer, instead operate as independent contractors, freelancers, or self-employed professionals who navigate multiple income streams. This model appeals to those seeking autonomy and flexibility but also exposes them to precarious conditions, including income instability, lack of social protections, and algorithmic control by platform providers.

As the gig economy matures, it increasingly intersects with more traditional employment structures, resulting in hybrid employment models. In these arrangements, individuals often hold a conventional job—such as a salaried position in a company or institution—while simultaneously engaging in freelance, remote, or platform-based work. An educator might teach full-time at a university while offering courses through online learning platforms. A software engineer employed by a firm may also take on contract work for clients abroad. Organizations, in turn, are adapting by constructing hybrid workforce ecosystems, composed of permanent staff, freelance collaborators, gig workers, and digital tools such as AI and data analytics platforms. This modular and fluid approach to labor allows firms to respond more rapidly to market demands, optimize costs, and access a broader pool of global talent.

However, the growing complexity of hybrid work and gig-based engagement brings to the forefront a crucial issue: the skillsets required to navigate this environment successfully. While technical competencies remain essential, particularly in data analysis, IT, or digital marketing, the hybrid-gig economy strongly privileges a combination of soft and analytical skills—a dual competence model that increasingly defines employability.

Soft skills—such as communication, adaptability, emotional intelligence, teamwork, and problem-solving—are indispensable in settings where individuals must manage multiple roles, collaborate across digital platforms, or deliver services to diverse clients without direct supervision. In a fragmented and highly personalized work environment, success often depends not only on what one can do, but on how one relates to others, builds trust, and adapts to shifting expectations. Freelancers working through gig platforms, for example, must establish rapport quickly, manage feedback loops, and maintain reputations across projects, often without institutional support.

At the same time, analytical skills are critical in a labor market shaped by data, automation, and decision-making under uncertainty. Whether it's understanding performance metrics, interpreting client requirements, navigating platform algorithms, or leveraging insights from user data, workers must be capable of critically engaging with information and applying it to solve complex problems. The gig and hybrid economy reward those who can work

independently, manage risk, and think strategically—traits associated with high levels of cognitive and analytical ability.

Furthermore, the very structure of hybrid and gig work often requires individuals to function as entrepreneurs of the self. This means not only delivering a specific task or service but also managing one's personal brand, portfolio, pricing, contracts, time, and professional development. The ability to self-assess, identify emerging trends, and invest in continuous upskilling becomes a vital form of labor capital. Soft and analytical skills intersect here: workers must not only acquire knowledge but also communicate its value, form networks, and negotiate ever-changing work arrangements.

In this new landscape, educational systems and labor policies face the challenge of adaptation. Traditional models of vocational preparation, based on clear occupational roles and hierarchical advancement, no longer suffice. There is a growing need for integrated skill development approaches that combine technical knowledge with interpersonal competencies and data literacy. Likewise, policy frameworks must evolve to offer social protections that are portable and inclusive, recognizing the legitimacy of hybrid and gig-based labor arrangements. This includes rethinking access to healthcare, pensions, and unemployment insurance for those working across multiple platforms or combining employment types (see more: De Stefano, Aloisi, 2022).

Concerning new technologies' labour market impacts, the analysis identifies increased IT specialist demand, especially in developed regions. Research confirms the rising trend in IT-related occupations and technology-driven job creation despite potential traditional sector job losses. This article validates the thesis of increasing IT influence on Poland's labour market transformation, highlighting critical IT sector changes and the imperative of aligning workforce competencies with knowledge-based economy demands. Technological transformation is ongoing, necessitating actions in education, continuous learning, and labour market policy areas.

Discussion

The findings affirm the partial applicability of the RBTC and ALM frameworks to the Polish context. While employment polarization aligns with theoretical expectations, unique national conditions—including delayed digitalization in rural areas and cultural-political legacies—moderate the scale and pace of change. Comparative analysis with Arendt and Grabowski's task-based wage assessments confirms these deviations.

Technological advancement presents a paradox: while displacing some forms of labour, it simultaneously creates new roles that require continuous upskilling. The growing importance of soft skills, adaptability, and digital literacy underscores the urgency of reforming educational and vocational systems.

Poland's situation mirrors broader global trends, yet local institutional responses—particularly in lifelong learning, labour market flexibility, and social protections—remain underdeveloped. Addressing the NEET phenomenon and ensuring equitable access to reskilling opportunities are among the most pressing priorities

Conclusions

- Polarization is clearly evident, with an increasing concentration of employment in high-skill analytical and interpersonal tasks and a stable demand for certain low-skill manual roles.
- Routine jobs—especially mid-skilled clerical and production occupations—have declined in relative share, although wage data reveal anomalies such as rising incomes among certain routine manual workers, likely reflecting labour shortages or collective bargaining outcomes.
- The IT sector has been the principal engine of job creation, particularly in urban areas, driven by remote work possibilities and increasing digital service demands accelerated by the COVID-19 pandemic.
- Disparities across regions are growing; large agglomerations like Warsaw, Kraków, and Wrocław exhibit greater adaptability and technological absorption compared to smaller towns and rural areas.
- Labour market polarization in Poland reflects global structural trends but manifests uniquely across task categories and regions.
- Technological transformation enhances the demand for IT and digital skills, increases work flexibility, and elevates the role of non-routine cognitive tasks.
- Regional labour market segmentation intensifies due to unequal access to digital infrastructure and educational resources.
- Policymaking must integrate flexible, inclusive, and forward-looking strategies to manage the disruptions and opportunities arising from digital transformation.

In response to the labour market transformation driven by digital and information technologies, policymakers, educational institutions, and employers in Poland should consider the following targeted strategies:

1. Reform of Lifelong Learning and Education:
 - Curriculum Modernization: Integrate digital skills, coding, data literacy, and AI awareness into all levels of education.
 - Task-based Learning: Align vocational and higher education more closely with the typology of tasks (e.g., cognitive vs. routine) based on ALM and RBTC models.
 - Teacher Reskilling: Provide ongoing training for educators to adapt to rapidly changing workforce skill needs.
2. Labour Market Adaptation Policies:
 - National Upskilling Programs: Launch publicly funded, modular training initiatives targeting workers in mid-skilled routine occupations at risk of automation.
 - Incentivize Flexible Work: Encourage flexible and remote work practices, especially in regions with poor access to high-skill jobs.
 - Support for NEET Youth: Develop specialized interventions to reintegrate NEET populations, combining employment pathways with digital competency development.
3. Regional Digital Inclusion:
 - Bridge the Urban-Rural Divide: Invest in digital infrastructure and mobile training units in rural areas and small towns.
 - Smart Specialization Strategies: Align regional development plans with high-demand ICT-related sectors (e.g., cybersecurity, green tech).
4. Labour Market Forecasting and Monitoring:
 - Data-Driven Policy Design: Establish a real-time labour market observatory using data analytics and AI to track skills shortages, job displacement risks, and emerging occupations.
 - Public-Private Collaboration: Foster partnerships between government, universities, and employers to pilot innovation labs, job transition schemes, and internship networks.
5. Social Protection and Worker Transition:
 - Reform Unemployment Insurance: Link benefits more closely with mandatory retraining programs.
 - Support Transitional Careers: Provide counseling, digital portfolios, and mobility grants for workers switching sectors.

By contextualizing Poland's labour market evolution within global technological shifts, this article underscores the importance of proactive policy design and institutional agility. A digitally inclusive future demands strategic foresight, cross-sector collaboration, and continuous investment in human capital.

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THE IMPACT OF SUSTAINABLE DEVELOPMENT ON THE RETURN ON EQUITY (ROE) AND CAPITAL EXPENDITURE (CAPEX) IN MINING COMPANIES IN EUROPE

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Purpose: The main objective of the article is to investigate whether the implementation of ESG policies affects the return on equity (ROE) and capital expenditure (CAPEX) in European mining companies in the years 2017-2023.

Design/methodology/approach: The study was conducted on mining companies from Europe. The main tool of the analysis is the OLS (Ordinary Least Squares) model with heteroscedasticity correction to examine the relationship between ROE, capital expenditure and ESG indices and control variables.

Findings: The research results indicate a statistically significant, but unexpected negative impact of ESG policies on the analyzed financial indicators in mining companies. A small but statistically significant negative impact of ESG policy implementation on ROE was found. The impact of ESG policies on capital expenditure (CAPEX) is even stronger and also negative.

Research limitations/implications: Due to the time-limited nature of the research sample, the conclusions drawn are relatively short-term.

Practical implications: The authors point to the need for a cautious interpretation of ESG effectiveness in capital-intensive industries. Although ESG policy is increasingly recognized as an integral element of financial analysis and has a positive impact on investment attractiveness and resilience to external shocks in the long term. This is of great importance to investors and market analysts.

Originality/value: Despite the growing importance of ESG issues, there is still a lack of clear and widely documented empirical evidence on the impact of implementing sustainability policies on key financial indicators of companies, especially in high-carbon industries such as the mining sector. The results can be an important contribution to the debate on the role of sustainability in shaping investment decisions and financial strategies of companies.

Keywords: Sustainable development, CAPEX, profitability, ROE.

Category of the paper: Research paper.

1. Introduction

Contemporary conditions for conducting business are increasingly shaped by the ideas of sustainable development, social responsibility, and the growing expectations of stakeholders in terms of transparency and corporate responsibility (Ahmadu et al., 2025). One of the key tools for assessing these aspects is the environmental, social, and governance indicator (ESG), which allows the analysis of the impact of a company's activities on the natural environment, society, and the quality of the organisation's management. ESG indicators are also increasingly becoming an element of financial analysis, used by investors and analysts to assess the long-term attractiveness and investment risk of a given entity (Kandpal et al., 2024).

Despite the growing importance of ESG issues, there is still a lack of clear and widely documented empirical evidence that confirms the impact of implementing sustainable development policies on key financial indicators of companies, especially in high-emission industries such as the mining sector. Mining activities, on the one hand, have a significant impact on the natural environment and local communities and, on the other hand, generate high profits and require intensive investment. Therefore, implementing ESG policies in this industry may involve significant strategic and financial dilemmas. The objective of this article is to analyse the impact of implementing ESG policies on return on equity (ROE) and capital expenditure (CAPEX) in European mining companies in the years 2017-2023. The adopted research period includes the years in which these companies began to systematically report non-financial data in line with ESG guidelines, which allowed for a reliable quantitative analysis. The study was carried out based on annual data from the S&P Global Market Intelligence database, and panel regression models with fixed effects were used for the analysis, which allow the specificity of individual companies. The analysis paid special attention to the relationship between the ESG indicator and the CAPEX level in the short term (current) and medium and long term (3 and 5 years). Furthermore, the impact of ESG policy on return on equity was analysed, taking into account a number of control variables such as financial leverage, current liquidity, and asset turnover. The results of the study provide new information on the consequences of implementing ESG policy in a sector with particular socio-environmental sensitivity and can be an important contribution to the debate on the role of sustainable development in shaping investment decisions and financial strategies of companies.

2. Literature review

2.1. The relationship between ROE (Return on Equity) and the level of a company's involvement in ESG policy

From the perspective of investors, the relationship between ROE (Return on Equity) and the level of a company's involvement in ESG policy (Environmental, Social, Governance) is crucial for assessing the investment attractiveness of a company (Ahmadu et al., 2025). ROE, as a measure of the efficiency of using equity capital, allows investors to assess how effectively management creates value for shareholders (Keter et al., 2023). Combined with the analysis of ESG factors, it provides a more complete picture of the company's risks and growth potential in the medium and long term (Chen et al., 2023; Wang et al., 2024).

For a growing number of investors, especially institutional ones, ESG is no longer just an add-on, but an integral element of financial analysis. It is recognised that companies with high ESG standards are better managed, more resistant to external shocks (e.g., regulatory, environmental, reputational) and achieve more stable and sustainable rates of return in the long term (Fafaliou et al., 2022). Investors pay attention not only to the direct level of ROE, but also to whether it is achieved at the expense of the environment, ethics, or corporate governance (Zhou et al., 2022; Zumente et al., 2021).

However, in the short term, the implementation of ESG policies can cause a decline in profitability indicators, including ROE (Ali et al., 2025; Yavuz et al., 2025). This is due to the fact that pro-environmental or social activities often require significant investment outlays and changes in the operating model, which do not bring immediate financial effects (Muyiwa-Ajayi et al., 2024; Cristea et al., 2024). For some investors focused on quick profits, this may be a negative signal, suggesting reduced capital efficiency.

Despite this, the dominant trend in financial markets is the growing recognition that ESG and ROE are not opposite, but complementary (Candio, 2024). More and more empirical studies confirm that socially and environmentally responsible companies achieve higher ROE in the long term, among others, because of reducing risk costs, improving stakeholder relations, customer loyalty, and easier access to cheaper capital (Chiomg, 2010; Saleh et al., 2011; Serzante et al., 2024; Ali et al., 2025; Muyiwa-Ajayi et al., 2024).

2.2. CAPEX as a Source of Sustainable Development of an Enterprise

Capital expenditure (CAPEX), understood as investment investments in fixed assets of an enterprise, plays a key role in the implementation of the sustainable development strategy (Kwistianus, 2022). They constitute the foundation for the transformation of an organisation towards a more effective, innovative, and responsible operating model. In the context of environmental, social, and governance (ESG), CAPEX can be perceived not only as an indicator of the company's development capacity but also as a real tool for implementing changes in the

scope of limiting the environmental impact, improving working conditions, or strengthening corporate governance (Myronchuk et al., 2024).

Capital investments, including the purchase of modern energy-saving technologies, the development of low-emission infrastructure, or the digitisation of operational processes, contribute to the achievement of environmental goals. At the same time, they allow for increased operational efficiency and reduce risks related to non-compliance with environmental regulations (Mousse et al., 2023). From a social point of view, CAPEX can be directed toward improving the safety and quality of the working environment, resulting in greater employee satisfaction and the building of a positive image of the company (Huang et al., 2023; Kwistianus, 2022; Haga et al., 2024).

In the long term, appropriately targeted capital expenditures become an important factor in building a competitive advantage based on ESG values (Zumente, Bistrova, 2021). Companies that systematically invest in durable and sustainable resources demonstrate greater resilience to market changes and are also better perceived by institutional investors, who are increasingly guided by sustainable development criteria when allocating capital (Panagopoulos, Tzionas, 2023; Muiyiwa-Ajayi et al., 2024).

However, it should be noted that the effectiveness of pro-ESG CAPEX depends on a coordinated strategic approach. Investments must be consistent with the goals of sustainable development, but also economically rational so that they do not disrupt financial liquidity and do not lead to excessive capital burdens (Amin et al., 2025; Zhou et al., 2022). Therefore, companies must balance the pursuit of ESG goals with an analysis of the return on investment (ROI), the life cycle of the project, and its impact on profitability (Saleh et al., 2023; Wanday et al., 2022).

CAPEX plays a central role in the implementation process of sustainable development (Myronchuk et al., 2024; Parapat, Ruhayat, 2024). It is a mechanism enabling the permanent transformation of the company's structure, provided that it is used in a strategic, coordinated manner and in line with long-term ESG goals (Chiucchi et al., 2025).

ESG policies offer long-term value creation and risk mitigation, their effective implementation remains challenged by short-term financial pressures, high initial investment costs, and the need for strategic alignment between sustainability goals and economic performance. Despite the long-term benefits of integrating ESG policies into corporate strategy, companies face significant challenges such as balancing short-term profitability with sustainability investments, ensuring economic rationality in ESG-driven CAPEX, and aligning stakeholder expectations with long-term value creation.

3. Research methodology

The study was carried out on a group of mining companies operating in Europe. The period from 2017 to 2023 was adopted for the study because these companies reported their ESG activities only from 2017.

The study used annual data. All data used in the study came from the S&P Global Market Intelligence database. The companies qualified for the study were all companies operating in Europe, classified by S&P Global Market Intelligence to the Industry Classification In (Primary) Oil, Gas and Consumable Fuels sector. This sector includes, among others, mining companies specializing in the extraction of coal, iron ore or copper, natural gas or crude oil. These companies also had to be active on the market/operating for the entire analyzed period. Prices were adjusted for changes in equity, such as subscription rights, dividends, and splits. The following data were used for the calculations:

- Pref – measured using ROE, CAPEX, CAPEX 3YGr, CAPEX 5YGr.
- ESG Index – The S&P Global Market Intelligence ESG Index includes all disclosures on environmental factors, social, and governance indicators of the company (i), in period (t).
- Lev – financial leverage; control variable measured as the ratio of total debt to total assets of the firm (i) in period (t) (Hamdana, 2020).
- Turn(TA) – asset turnover, measured by net sales as a percentage of total assets.
- CR – current liquidity ratio.

Capital expenditure (abbreviated as ‘CAPEX’) is a payment made in cash or credit to purchase long-term physical or fixed assets used in the firm’s operations. The expenditure is capitalised (that is, not recorded directly in the firm’s income statement) on the balance sheet and is considered an investment by the firm in expanding its operations (Olayinka, 2022; Grozdić et al., 2020).

CAPEX is important for firms to expand and maintain their operations by investing in new properties, plants, equipment, products, and technologies. Financial analysts and investors pay special attention to a firm’s capital expenditure because it does not initially appear on the income statement but can have a significant impact on cash flows (Jiang et al., 2023; Fridson, Alvarez, 2022).

The table below presents the data data statistics for the analysed used in the study.

Table 1.*Summary statistics of all variables*

	Mean	Median	Max	Min	S.D.
CR	1.365	1.282	3.070	0.419	0.466
ROE	11.042	10.599	95.658	-315.796	38.484
Turn(TA)	0.976	0.742	3.975	0.113	0.805
ESG Index	53.230	53.000	86.000	22.000	15.922
Lev	61.236	60.077	109.118	33.037	13.588
CAPEX	-3945170.168	-875739.665	-3412.988	-23011000.000	5933579.589
CAPEX 3YGr	2.787	-0.541	77.119	-71.373	22.698
CAPEX 5YGr	2.759	1.454	87.310	-63.113	17.760
CR	1.365	1.282	3.070	0.419	0.466

Source: own study.

The following hypotheses were tested in the study.

1. The ROE indicator is affected by the company's ESG policy.
2. The CAPEX indicator is affected by the company's ESG policy.
3. The CAPEX indicator over a 3-year period is affected by the company's ESG policy.
4. The CAPEX indicator over a 5-year period is affected by the company's ESG policy.

The analysis related to the companies' preferences regarding the impact on ROE and CAPEX was presented in the form of parameter estimation of OLS models with heteroskedacity correction and panel models. The study used cross-sectional regression analysis and panel data. Tests were also conducted for the presence of fixed and random effects (redundant fixed effects - Wald test, random effects - Breusch-Pagan test).

The model for the total sample is presented in Equation 1.

$$Pref_{it} = \alpha_0 + \alpha_1 ESG_{it} + \alpha_2 CR_{it} + \alpha_3 Turn(TA)_{it} + \alpha_4 Lev_{it} + \varepsilon_{it} \quad (1)$$

4. Research results

After conducting a descriptive analysis of the variables and testing the assumptions of the regression analysis, we use regression analysis to examine the impact of the ESG index [independent variables] on ROE, capital expenditure in the current period and in the period of 3 and 5 years [dependent variables]. First, using the OLS model with heteroskedasticity correction, we examine the relationship between ROE, capital expenditure in the current period and in the period of 3 and 5 years, and ESG indices and control variables using equation 1.

To analyse the model specification, we also used the RESET test, which showed the precision of the applied model (p value > 0.05). The results obtained from the RESET test show that the model specification of the variables is correct. The results of this estimation are presented in Table 2.

Table 2.*Estimation of model parameters from equation (1) using the OLS method*

	ROE	CAPEX	CAPEX 3YGr	CAPEX 5YGr
const	38.380 **	-3.783	41.411 **	34.360 ***
Lev	-0.6253 ***	33054.6	-0.4795 **	-0.4276 ***
Turn (TA)	11.480 ***	803094***	1.69	9.296 ***
CR	9.690 *	1000310.00	7.155	-0.2463
ESG Index	-0.223 *	-63860.3***	-0.339 **	-0.242 ***
R2	27%	23%	13%	25%

Note: ***/** Indicators are significant at 10% / 5% / 1% respectively.

Source: own study.

As can be seen, the variable related to the applied ESG policy has a statistically significant impact on all the indicators analysed. Interestingly, this impact is negative, suggesting that a greater application of ESG-related policies will reduce the indicators analysed. In the case of the ROE indicator, we observe a small but statistically significant negative impact of the application of ESG policies in mining companies. As for capital expenditure, the impact of ESG policies is stronger here, but also negative. This suggests that increasing the impact of ESG policies will result in a reduction in capital expenditure (both current and in the 3 and 5-year periods).

When analysing the control variables, the greatest impact on CAPEX (both current and in the 3 and 5 year periods) is exerted by variables related to asset turnover, measured by net sales as a percentage of all assets, and financial leverage. In the case of ROE, all control variables have a statistically significant impact on its value.

Then, tests were conducted for the presence of fixed and random effects (redundant fixed effects, Wald test, random effects, Breusch-Pagan test). Cross-sectional regression analysis was performed by estimating models with fixed and random effects for various combinations of effects. Since the models with random effects did not provide statistically significant results, only the models with fixed effects were subjected to further analysis. The results obtained in the panel analysis confirmed the results obtained in the previous models.

5. Discussion and Conclusions

The results of the conducted analyses indicate a statistically significant impact of ESG policy on the analysed financial indicators in mining companies, however, the direction of this impact is unexpected - negative. This means that intensification of activities consistent with ESG policy is associated with a decrease in the value of indicators such as ROE (Return on Equity) or the level of capital expenditure (CAPEX). In particular, although the impact on ROE is relatively small, it remains statistically significant, indicating the durability of this relationship in the studied group of companies. An even more pronounced effect was observed in relation to capital expenditure - both current and in longer periods (3 and 5 years) - where

ESG policy shows a strong, negative impact, suggesting a reduction in capital investments as the commitment to sustainable development increases. These findings are consistent with previous studies presented by Yavuz et al. (2025), Zhou et al. (2022) and Chen et al. (2023).

Interpreting these results requires taking into account the characteristics of the mining industry, which is capital intensive and is particularly exposed to increasing costs related to environmental, social, and corporate governance regulations. Implementing ESG policies can require incurring costs of operational transformation, implementing new technologies, restructuring processes, or limiting activities in areas considered incompatible with the principles of sustainable development. As a result, companies can decide to limit investments or allocate funds to activities that are less profitable in the short term, affecting the decrease in capital efficiency indicators.

However, contrasting cases within the sample reveal that some mining companies (as Galp Energia, MOL, OMV, Energies SE) with high ESG performance have maintained stable or even improved ROE and CAPEX levels, suggesting that the negative relationship is not consistent across the sector. These exceptions may indicate the presence of moderating factors, such as access to green financing, proactive stakeholder engagement, advanced ESG integration strategies, or geographic advantages tied to more supportive regulatory environments. Recognising these divergences underlines the need for a more granular understanding of the conditions under which ESG initiatives can enhance or hinder financial performance.

At the same time, the results of the analysis of control variables indicate that the level of investment expenditure is significantly affected by asset turnover indicators and financial leverage, which confirms that the structure of the balance sheet and the efficiency of asset management remain key determinants of investment decisions regardless of the ESG policy. In the case of ROE, all control variables demonstrate statistical significance, which confirms the complexity and multifactorial nature of the mechanisms shaping the return on equity. These findings are consistent with previous studies presented by Grozdić et al. (2020) and Parapat et al. (2024).

The Wald and Breusch-Pagan tests, as well as a comparison of regression models with fixed and random effects, clearly indicate the superiority of models with fixed effects in the context of the quality of fit and the significance of the results. This confirms that the specificity of individual companies plays a key role in shaping the relationship between ESG and financial performance, which supports the need to take into account individual effects in panel studies. In summary, the results obtained indicate that in the mining sector, increased participation in ESG policy can be associated with a short-term decrease in financial indicators such as ROE and CAPEX. This may result from the costs of adapting to the requirements of sustainable development and changes in the investment profile of companies. However, the presence of high-performing ESG firms that defy this trend suggests the need for a more differentiated analysis. These findings highlight the importance of cautious interpretation of ESG effectiveness in capital-intensive industries and call for further research into long-term outcomes and firm-specific ESG strategies.

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**FINANCIAL SECURITY UNDER ECONOMIC PRESSURE:
OLS AND ARMAX ANALYSIS OF MACROECONOMIC
STABILIZATION IN HEALTHCARE SECTORE**

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Purpose: The objective of this article is to comprehensively assess the financial security of the Polish healthcare sector over 15 years, taking into account both internal measures of financial efficiency and the impact of macroeconomic conditions.

Design/methodology/approach: The paper uses a synthetic indicator of financial security (HealtFinSec), constructed using the TOPSIS method and the OLS and ARMAX econometric models. Particular emphasis is placed on examining the role of macroeconomic stabilisation (MSP) as a factor determining the financial security of the sector.

Findings: The results of the study indicate that the long-term financial stability of the health sector depends not only on internal management, but also on the overall macroeconomic situation of the country. This means that health care financing planning should be integrated with the state's economic policy. The practical consequence is the need to build buffer mechanisms, e.g. stabilisation funds – that will increase the resilience of the system in periods of recession.

Research limitations/implications: The availability of data, the choice of normalisation method and the choice of research sample.

Practical implications: For decision makers, this means the need for long-term planning and strengthening of tools to monitor the condition of the sector in a dynamic approach. These conclusions may also be helpful for medical facilities, indicating the importance of liquidity management, operational efficiency, and debt reduction. For international institutions and regulators, the article provides arguments for a better linking of health policy with the goals of sustainable development and economic stability.

Social implications: The social implications of the article relate to the health security of citizens, the role of economic policy in shaping quality of life, and the need for systemic changes in the financing of the health care sector in Poland. The results provide a strong argument for long-term coordinated public policy that integrates health and economic goals.

Originality/value: The novelty of the article is the multidimensional, quantitative, and dynamic approach to the financial security of the health sector and its innovative link to macroeconomic stability – using advanced analytical methods (TOPSIS, ARMAX) and a long-term time perspective. This article makes an original contribution to research on the economics of the health care sector, indicating the need for a systematic approach to assess its financial stability, in connection with macroeconomic conditions and long-term financing and management strategies.

Keywords: ARMAX analyse, healthcare sector, financial security, macroeconomic stability.

Category of the paper: Research paper.

1. Introduction

The financial stability of the healthcare sector is the foundation for its effective functioning, especially in public systems, where the balance between the quality of services and budget constraints is a key challenge (Longo, Saadati, 2025). In Poland, as in many other countries, the healthcare sector is strongly dependent on political decisions, available public funds, and the general macroeconomic condition of the country (Nojszewska, Sielska, 2022). Analysis of the financial security of the healthcare sector in the years 2008-2023 allows a better understanding of how economic variables and internal financial parameters affected its long-term stability.

The period covered by the study includes both the global financial crisis (2008-2010) and the COVID-19 pandemic (2020-2021), which were serious stress tests for the healthcare system. Despite these challenges, the financial liquidity indicators (CR and QR) remained at a satisfactory level, indicating the ability of the entities to settle short-term liabilities. However, at the same time, profitability indicators such as ROS, ROA, and ROE remained low throughout the analysis period, which suggests permanent structural limitations in the generation of financial surpluses.

The objective of this article is to comprehensively assess the financial security of the Polish healthcare sector over 15 years, taking into account both internal measures of financial efficiency and the impact of macroeconomic conditions. The paper uses a synthetic indicator of financial security (HealtFinSec), constructed using the TOPSIS method and the OLS and ARMAX econometric models. Particular emphasis is placed on examining the role of macroeconomic stabilisation (MSP) as a factor determining the financial security of the sector.

HealtFinSec is a synthetic indicator used for comprehensive assessment of the level of financial security of entities operating in the healthcare sector. It takes into account a set of key financial indicators describing liquidity, debt, operational efficiency and profitability. The purpose of HealtFinSec is to capture the overall level of the entity's ability to operate safely, meet financial obligations, undertake investment activities and respond to changes in the macroeconomic environment. This indicator can be constructed as a normalized value

calculated based on the weights assigned to individual components (e.g. current financial liquidity, debt level, operating margin, receivables turnover), adapted to the specifics of the healthcare sector.

This study makes a significant contribution to the debate on sustainable healthcare financing in Poland and is a valuable source of knowledge for policy makers, healthcare facilities, and health economists interested in the long-term resilience of the system to external shocks.

2. The Role of Financial and Macroeconomic Stability in Ensuring Enterprise Security and Sustainable Growth - literature review

Financial security is currently the most important component of the economic security of an enterprise (Raczkowski, 2014). In the literature, it is defined in various ways. In a narrow sense, an enterprise's financial security means maintaining an appropriate surplus of current assets over short-term liabilities (Wędzki, 2003) or maintaining financial liquidity and high management efficiency (Franc-Dąbrowska, 2006). In a broad sense, it is identified with a situation that enables the company's current operations and development (Karbownik, 2012), with access to resources and the market for selling products (Górczyńska, Zadora, 2014).

Considering the financial security of an enterprise, several aspects should be noted:

- a company's financial security is a component of its economic security,
- it is a process that ensures the protection of the financial interests of the company,
- it is one of the factors of the company's growth and its stability,
- it can be characterized by a combination of selected indicators (Delasa et al., 2015).

These indicators include primarily: financial liquidity, operational efficiency, debt and profitability (Kowalska, Misztal, 2020).

The choice of the right indicators for assessing financial security should be consistent with the features of the enterprise's functioning: meet strategic goals, consider the peculiarities of the composition and structure of funding sources, reflect the specifics of the industry and the individual level of profitability (Dokiienko et al., 2024).

It should be emphasized that financial security refers to two fundamental issues in the functioning of a company: financial stability and financial independence (Nguyen, Nguyen, 2020). Financial security is ensured not only by maintaining a stable financial position but also by the strategic development of the enterprise and the creation of conditions for implementing a financial mechanism capable of adapting to future changes in the internal and external environment (Postolache, 2025). Ensuring financial security should be based not on the separate process but on the system of interconnections of all processes that occur within and outside the enterprise's boundaries in interaction with the external environment (Tursunov, 2020). An important element of this environment is the macroeconomic environment and its stability.

Macroeconomic stability is an ambiguous and hard-to-define concept. In a broad sense, it is understood as a configuration of social, political, economic, demographic, military, and natural and climatic indicators that determine economic growth (Raczkowski, Komorowski, 2023; Siddik, 2023). This concept is often based on the evaluation of several key macroeconomic indicators. These include GDP growth, unemployment rate, inflation rate, the budget balance of the state to GDP, and the balance of the current turnovers size to GDP (Kamguia et al., 2024). Some studies propose a broader concept encompassing price stability and fiscal prudence, well-functioning real economy, sustainable debt levels, and healthy private and public sector balance sheets (Wielechowski, 2024).

Macroeconomic stability is achieved when public policies lead to strong growth, low inflation, low unemployment, and a balance of payments position that does not lead to disruptive exchange rate movements (Kireyev, 2025). The OECD defines macroeconomic stability as avoiding significant fluctuations in economic activity, particularly regarding GDP growth, inflation, and unemployment rates. It also emphasizes the role of fiscal and monetary policies in achieving this stability (Sutherland, Hoeller, 2014).

Macroeconomic stability exists when key economic relationships are in balance. These relationships, however, need not necessarily be in exact balance. Imbalances such as fiscal and current account deficits or surpluses are perfectly compatible with economic stability, provided they can be financed sustainably (Ames et al., 2001). The objective of macroeconomic stability is not merely the maintenance of such stability but rather the advancement of the population's well-being and the state's economic growth. Macroeconomic stability can be regarded as a public good, facilitating the achievement of stable well-being, confidence in the future for the entire society, and the success of long-term investment projects (Bilenko, 2024). This stability affects the quality of the business environment (Mac Clay et al., 2023), eliminates uncertainty in economic activity, increases the country's investment attractiveness, and increases the probability of future economic activity growth. In a situation of increasing macroeconomic instability, uncertainty and risk aversion increase among investors (Janecki, 2017; Aghion, Howitt, 2006). Macroeconomic stability significantly affects financial development in the region (Ehigiamusoe et al., 2020), and it is also critical for peace (Kireyev, 2025). It has an important bond to economic growth. According to the economic consensus, macroeconomic stability is a necessary, although not sufficient, condition for achieving high and sustainable economic growth (Arriaza-Herrera, Castillo-Maldonado, 2022).

The research shows a significant impact of macroeconomic stability indicators on economic growth after the 2008 global financial crisis, compared to a very small impact during the 2000-2008 boom (Bilenko, 2024). The financial crisis had particularly negative consequences in countries with high levels of debt and deficit, which also affected the healthcare sector (Hnatyszyn-Dzikowska, 2013). Macroeconomic instability and financial crises had a multidimensional impact on the functioning of this sector (Kaplan, 2012; Mladovsky et al., 2012). Maintaining macroeconomic stability is important because it helps generate higher and

more predictable budget revenues, facilitating the financing of public healthcare systems and investments in infrastructure, technology, research, and preventive programs. In a stable macroeconomic environment with a high level of employment, more people have insurance offered by their employer and/or can afford private insurance. Price stability facilitates healthcare cost planning and makes healthcare, including private care, more accessible to patients. Economic downturns usually force budget cuts, resulting in health service underfunding and reduced investment in healthcare infrastructure. Macroeconomic instability can lead to increased costs, limited access to health care, longer waiting times for medical services and a deterioration in their quality.

Macroeconomic stabilization can strengthen public management (Rackowski, 2016), which is possible thanks to increasing available financial resources and creating specific sectoral policies, including healthcare. The problem of financing the healthcare sector in Poland is becoming particularly important in the face of the financial gap in the healthcare system forecasted by the National Health Fund, which may amount to approximately PLN 250 billion in 2025-2028 (Dudek et al., 2025).

3. Research methodology

The objective of the investigation is to assess the impact of financial security on the healthcare sector in Poland from 2008 to 2023 and to determine the effect of macroeconomic stabilisation on the financial condition of the sector. Annual data were obtained from wskaznikibranzowe.pl and stat.gov.pl.

The following research questions were asked:

- How has the financial security of the Polish healthcare sector evolved between 2008 and 2023?
- What were the main changes in liquidity, profitability, operational efficiency, and debt during the analysis period?
- Is there a relationship between the level of macroeconomic stabilisation (MSP) and the financial security of the healthcare sector?
- Which financial indicators are most strongly correlated with the overall condition of the sector?
- What conclusions can be drawn from the OLS and ARMAX models regarding the impact of macroeconomic factors on the stability of the healthcare sector?

In the first step, financial indicators were selected and grouped into four categories.

- Liquidity: Current Ratio (FLI) and Quick Ratio (FFL).
- Profitability: Return on Sales (ROS), Return on Assets (ROA), and Return on Equity (ROE).
- Operational efficiency: Days Inventory Outstanding (DIO), Days Sales Outstanding (DSO), and Days Payables Outstanding (DPO).
- Debt: Debt Ratio (DR).

Based on these indicators, a synthetic financial security index for the healthcare sector (HealtFinSec) was calculated using the TOPSIS method, which allows comparison and ranking of years relative to an ideal financial condition.

In the next step, the Macroeconomic Stabilization Index (MSP) was calculated based on the concept of Grzegorz W. Kołodko's Macroeconomic Stabilization Pentagon. The MSP index includes five variables: real GDP growth rate, inflation rate (HICP), unemployment rate, current account balance as a percentage of GDP, and general government deficit as a percentage of GDP.

All variables were standardised, and the MSP index was calculated as the arithmetic mean of the five components. The MSP index reflects the general level of macroeconomic stability in a given year.

To examine the relationship between MSP and HealtFinSec, two econometric models were used:

- The Ordinary Least Squares (OLS) regression model to assess the direct impact of MSP on financial security.
- The ARMAX model also considers lagged effects and the influence of past economic shocks.

A correlation matrix was also constructed to analyse the strength and direction of the relationships between the individual financial indicators and HealtFinSec and MSP.

The models were evaluated in terms of:

- Statistical significance of coefficients (p-values).
- Goodness of fit (R-squared, AIC).
- Compliance with the assumptions of the classical model (White test, Durbin-Watson test, LM test, normality of the residuals).

The results of the analysis provided answers to the research questions. They allowed conclusions to be drawn about the financial condition of the healthcare sector and its sensitivity to macroeconomic changes in Poland between 2008 and 2023.

4. Research results

Table 1 presents the financial security of the Polish health sector for the years 2008-2023. The indicators are grouped into four categories: liquidity, profitability, operational efficiency, and debt. The liquidity indicators include the Current Ratio (FLI) and Quick Ratio (FFL). Throughout the period analysed, the FLI ranged from 1.13 in 2011 to 1.42 in 2021, while the FFL fluctuated between 1.02 (2011) and 1.28 (2021). These values suggest that the sector maintained a stable ability to meet short-term liabilities, with slight improvements in liquidity after 2020.

The profitability indicators – Return on Sales (ROS), Return on Assets (ROA), and Return on Equity (ROE) – remained lower overall. ROS was highest in 2021 (0.06) and lowest in 2011 and 2018 (0.01). ROA ranged from 0.02 to 0.08, peaking in 2008 and 2021. Similarly, ROE reached a high of 0.16 in both 2008 and 2021, reflecting occasional surges in profitability but a generally modest financial return.

Regarding operational efficiency, days of inventory outstanding (DIO) increased from 3.32 days in 2008 to a peak of 7.37 days in 2020 before declining to 4.66 in 2023. Days Sales Outstanding (DSO) showed a gradual increase from 41.34 days in 2008 to 49.80 in 2015, followed by a slight decrease to 41.78 in 2023. Days payables outstanding (DPO) peaked at 77.17 days in 2014 and declined to 59.67 days in 2023, indicating a more efficient payment cycle.

The Debt Ratio (DR) remained relatively stable over the years, ranging from 0.51 in 2018 to 0.59 in 2010. This indicates a moderate but persistent reliance on external financing within the sector.

Table 1.

The Financial Security of the Polish Health Sector from 2008 to 2023

	FLI	FFL	ROS	ROA	ROE	DIO	DSO	DPO	DR
2008	1.36	1.25	0.05	0.08	0.16	3.32	41.34	56.37	0.53
2009	1.31	1.20	0.05	0.07	0.15	3.67	42.11	61.77	0.57
2010	1.19	1.09	0.04	0.05	0.11	3.99	45.52	69.56	0.59
2011	1.13	1.02	0.01	0.02	0.04	4.47	44.25	73.19	0.58
2012	1.18	1.07	0.03	0.03	0.08	4.38	45.42	72.27	0.57
2013	1.30	1.18	0.03	0.03	0.07	4.68	46.42	69.52	0.55
2014	1.14	1.03	0.03	0.02	0.06	4.89	48.35	77.17	0.56
2015	1.38	1.26	0.03	0.03	0.06	5.01	49.80	67.88	0.56
2016	1.36	1.24	0.02	0.02	0.04	5.09	47.27	65.54	0.57
2017	1.29	1.17	0.02	0.02	0.04	5.05	44.47	70.25	0.56
2018	1.24	1.12	0.01	0.02	0.03	5.02	42.94	67.17	0.51
2019	1.30	1.18	0.02	0.02	0.05	4.95	44.83	66.22	0.53
2020	1.36	1.22	0.04	0.04	0.08	7.37	46.48	72.89	0.55
2021	1.42	1.28	0.06	0.07	0.16	6.54	43.14	64.43	0.54
2022	1.35	1.22	0.04	0.04	0.09	5.85	43.22	64.77	0.54
2023	1.41	1.27	0.05	0.07	0.14	4.66	41.78	59.67	0.54

Source: own elaboration based on wskaznikibranzowe.pl

The financial safety index was calculated using the TOPSIS method. It includes indicators of liquidity, profitability, debt, and working capital. The analysis covers the years 2008 to 2023 in the healthcare sector.

From 2008 to 2010, the financial condition was stable. Liquidity remained strong. The sector was resilient during the economic crisis. The index decreased slightly but remained at a reasonable level. From 2011 to 2016, financial safety weakened. Profitability was reduced. The levels increased. Liquidity and efficiency also decreased. This period reflects financial stress in the sector. Between 2017 and 2019, the situation improved slowly. Liquidity ratios increased. Receivables turnover became shorter. Profitability was still low, but financial safety stabilised. In 2020-2023, the index increased significantly. The best results were recorded in 2021 and 2023. Profitability and liquidity improved. The healthcare sector responded well after the COVID-19 crisis.

The years 2020 and 2021 were dominated by the pandemic and programs aimed at combating its economic consequences (Opolski, Zuber, 2023). Appropriate legal acts were adopted and financial measures were launched, including those from EU aid funds, to mitigate the effects of the COVID-19 pandemic (The Act of 2 March 2020 and the Act of 16 April 2020).

Overall, the index shows a U-shaped trend. After a decline, the financial safety of the healthcare sector improved. The sector became more stable and financially secure.

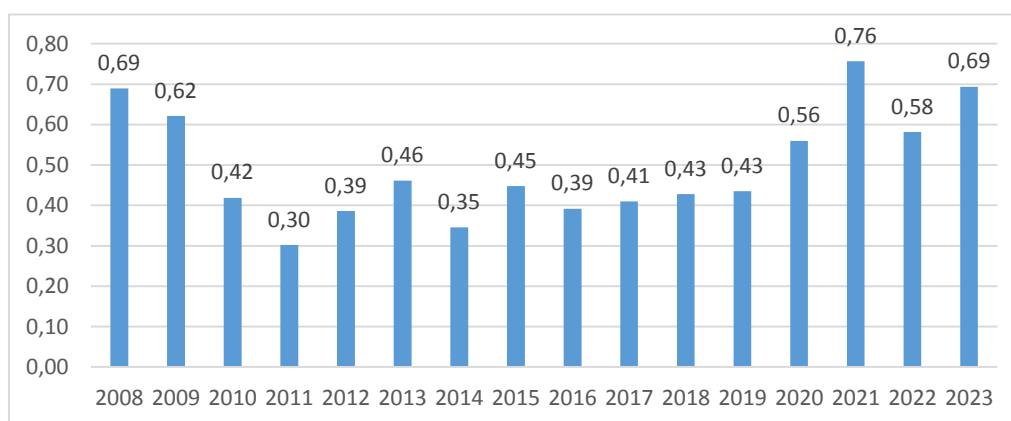


Figure 1. Financial security indicator from 2008 to 2023.

Source: based on wskaznikibranzowe.pl

The MSP index shows how stable the economy was each year (Figure 2). In 2008, the value was 0.38. It remained close to 0.40 for several years. In 2012, it dropped to 0.34, showing weaker stability. After 2012, the index started to rise. It reached 0.44 in 2015 and 0.48 in 2017 and 2018. This means that the economy became more stable during those years. In the last years, the index stayed between 0.42 and 0.45. In 2023, it was 0.39, a small drop.

Overall, macroeconomic stability improved after 2012 and remained at a good level in 2015-2020.

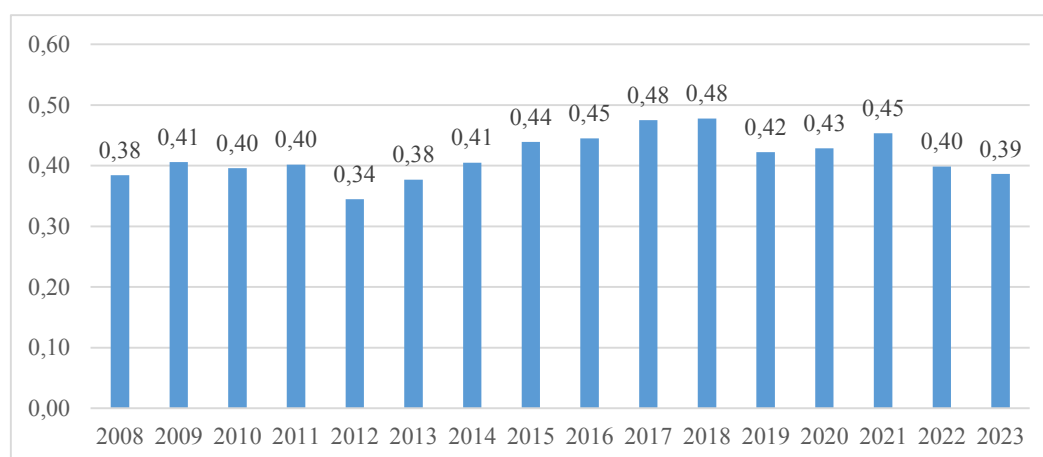


Figure 2. Macroeconomic Stabilisation Indicator from 2008 to 2023

Source: based on stat.gov.pl.

Figure 3 is a correlation matrix. It shows the strength and direction of the relationships between financial and performance indicators. Values range from -1 to +1. Red means positive correlation (variables increase together). Blue means negative correlation (one increases, the other decreases).

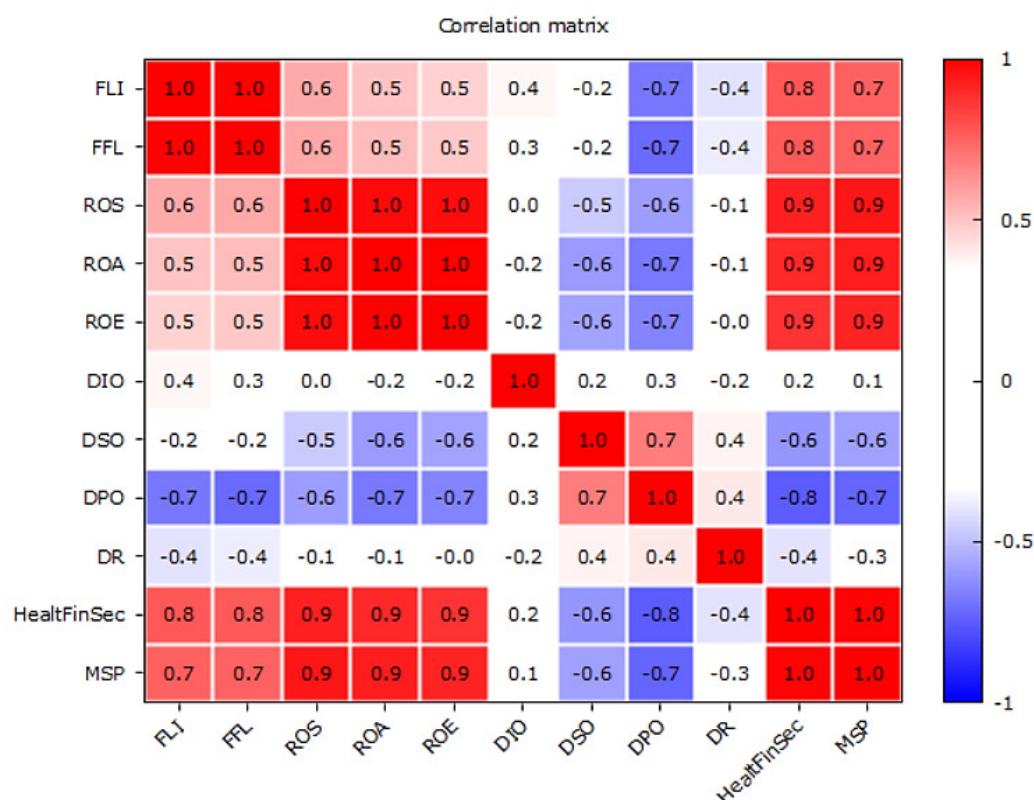


Figure 3. Correlation matrix from 2008 to 2023.

Source: based on stat.gov.pl

The diagonal shows values of 1.0 because each variable is perfectly correlated with itself. It shows that:

- FLI (Financial Leverage Index) and FFL (Firm Financial Leverage) are strongly and positively correlated (1.0). They both measure how much debt a company uses.
- ROS (Return on Sales), ROA (Return on Assets), and ROE (Return on Equity) show very strong positive correlations with each other (approximately 1.0). This means that if one type of profitability increases, the others also increase.
- These profitability indicators also have strong positive correlations with:
 - HealtFinSec (Health of Financial Security), showing that more profitable companies are also financially healthier.
 - MSP (Market Sustainability Performance), meaning that profitable companies also perform better in terms of long-term market goals.
- DPO (Days Payables Outstanding) has strong negative correlations with ROS, ROA, ROE, HealtFinSec, and MSP (around -0.7 to -0.8). This suggests that the desire to pay bills is related to weaker financial results.
- DSO (Days Sales Outstanding) negatively correlates with profitability and sustainability, but not as strongly as DPO.
- DR (debt ratio) shows moderate negative correlations with performance indicators, suggesting that higher debt levels can hurt company performance.
- The DIO (Day Inventory Outstanding) has weak correlations with most other variables. It does not have a strong effect on profitability or sustainability.

This matrix shows that high profitability goes hand in hand with strong financial health and sustainability. In contrast, high debt, long customer payment times, and delays in paying suppliers are related to poorer performance and weaker financial security.

Table 2 explains how MSP affects HealtFinSec. The constant (intercept) is 0.599. This means that if MSP is zero, HealtFinSec would be negative. The coefficient for MSP is 1.044. This is a strong and positive effect. When MSP increases by 1 unit, HealtFinSec increases by about 1.044 units. The p-value for MSP is very small (< 0.001). This means that the result is statistically significant. The R-squared is 0.979. This means that the model explains almost 98% of the variation in HealtFinSec. The model fits the data very well. The F test is also highly significant. This confirms that the model is overall useful. The Durbin-Watson statistic is 1.05, which suggests some autocorrelation in the residuals. However, the LM test for autocorrelation gives a p-value of 0.071, so autocorrelation is not highly significant. The White test for heteroskedasticity gives a p-value of 0.537, so there is no evidence of heteroskedasticity.

The normality test has a p-value of 0.121. This means that the residuals are likely to be normally distributed.

MSP has a strong and positive effect on HealtFinSec. The model is statistically strong, with no major problems in the residuals.

Table 2.*The OLS estimation Dependent variable: HealtFinSec*

coefficient	std. error	t-ratio	p-value

const	-0.599031	0.0433162	-13.83 1.48e-09 ***
MSP	1.04355	0.0410108	25.45 4.02e-013 ***
Mean dependent var 0.495375 S.D. dependent var 0.136710			
Sum squared resid 0.005933 S.E. of regression 0.020587			
R-squared 0.978836 Adjusted R-squared 0.977324			
F(1, 14) 647.4877 P-value(F) 4.02e-13			
Log-likelihood 40.49508 Akaike criterion -76.99016			
Schwarz criterion -75.44498 Hannan-Quinn -76.91103			
rho 0.451775 Durbin-Watson 1.046695			
White's test for heteroskedasticity - Test statistic: LM = 1.24229 with p-value = P(Chi-square(2) > 1.24229) = 0.537328			
Test for normality of residual - Test statistic: Chi-square(2) = 4.2296 with p-value = 0.120657			
LM test for autocorrelation up to order 1 - Test statistic: LMF = 3.87805 with p-value = P(F(1, 13) > 3.87805) = 0.0706122			

Source: own elaboration based on wskaznikibranzowe.pl; stat.gov.pl.

Table 3 shows ARMAX estimation. Results show a strong, statistically significant effect of MSP ($\beta = 1.014$, $p < 0.0001$), underscoring its key role in enhancing financial security. The constant term is negative and significant (-0.567 , $p < 0.0001$), suggesting low baseline financial security without external drivers. The AR term is insignificant ($\phi_1 = 0.173$, $p = 0.612$), while the MA term is marginally significant ($\theta_1 = 0.578$, $p = 0.056$), indicating some effect of past shocks.

Table 3.*The ARMAX estimation results; dependent variable: HealtFinSec*

	Coefficient	Std. Error	z	p-value
const	-0.567275	0.0482913	-11.75	<0.0001
phi_1	0.173044	0.340984	0.5075	0.6118
theta_1	0.578261	0.303188	1.907	0.0565
MSP	1.01446	0.0447676	22.66	<0.0001

Mean dependent var	0.495375		S.D. dependent var	0.136710
Mean of innovations	-0.000748		S.D. of innovations	0.015646
R-squared	0.986061		Adjusted R-squared	0.983917
Log-likelihood	43.50352		Akaike criterion	-77.00705
Schwarz criterion	-73.14410		Hannan-Quinn	-76.80923

		Real	Imaginary	Modulus	Frequency
AR	Root 1	5.7789	0.0000	5.7789	0.0000
MA	Root 1	-1.7293	0.0000	1.7293	0.5000

Source: own elaboration based on wskaznikibranzowe.pl; stat.gov.pl.

The model shows an excellent fit ($R^2 = 0.986$, adj. $R^2 = 0.984$; AIC = 77.01), with stability confirmed by the root moduli AR and MA exceeding 1. In general, MSP emerges as the dominant and stable driver of financial security in the sector.

5. Discussion

The evaluation of the financial security of the Polish healthcare system from 2008 to 2023 offers several vital trends and implications. The healthcare sector maintained good liquidity throughout the research period. The values of the Current Ratio (FLI) and the Quick Ratio (FFL) indicate that healthcare facilities were generally in a position to fulfil their short-term obligations even during such challenging periods as the global financial crisis (2008–2010) and the COVID-19 pandemic (2020–2021). Liquidity eased after 2020, providing a more solid post-pandemic recovery.

However, profitability was low, as return on sales (ROS), return on Assets (ROA), and Return on equity (ROE) were essentially at low levels. Profit peaks in 2008 and 2021 suggest that the industry is sporadically capable of improving its financials, especially when the macroenvironment is supportive. However, consistently low mean levels of profitability suggest structural obstacles in generating revenue and controlling costs in the public healthcare sector.

On an efficiency-of-operations basis, measures such as days inventory outstanding (DIO), Days Sales Outstanding (DSO), and days payables outstanding (DPO) capture the volatility of broader economic trends. The increase in DIO through 2020 and subsequent drop show efforts to streamline inventory management, possibly due to supply chain disruptions from the pandemic. Similarly, the trend for DPO shows that the industry became more efficient at paying suppliers after peaking in 2014.

The debt ratio (DR) was steady, reflecting a modest but persistent use of outside finance. This reflects the conservative approach of the sector to debt, likely due to the controlling factors and public sector finance mechanisms.

The synthetic financial security index (HealtFinSec), which was created using the TOPSIS method, showed a U shape in 15 years. The financial insecurity of 2011–2016 reflects financial stress, possibly due to increased public budget stringency and economic slowdown. The recovery after 2017, especially for years 2021 and 2023, reflects that the sector responded well to emerging new financial and operational issues.

A key finding of the study is the statistically robust and significant association between macroeconomic stabilisation (MSP) and financial security (HealtFinSec). The OLS and ARMAX models confirmed that MSP is an essential driver of economic security in the healthcare sector. As captured through real GDP growth, inflation, unemployment, fiscal balance, and current account balance, macro stability rises with the sector's financial strength. A healthy economic climate is crucial to maintaining the financing and performance.

The correlation matrix also reflects the centrality of profitability. ROS, ROA, and ROE have strong and positive correlations with HealtFinSec and MSP, reflecting that financial well-being is highly correlated with internal efficiency and macroeconomic external variables. However,

indicators such as DPO and DR have negative correlations with performance measures, reflecting that the longer the payment days and the higher the debt needed, the worse the finances are.

The ARMAX model also sheds more light by incorporating time dynamics. Although the moving average term was not significant, the autoregressive term was significantly just, referring to the presence of follow-through influences from past economic shocks still having some impact on present-day financial performance. However, the MSP continued to be the most influential and stable explanatory variable.

All in all, the evidence suggests that macroeconomic conditions have a crucial influence on the fiscal sustainability of the health sector. Financial stability is vital for policy makers in planning reforms and budgeting. Enhanced profitability and efficiency through focused initiatives could further boost the sector's resilience to external shocks.

6. Conclusions

The research confirms that the financial stability of the Polish healthcare sector in 2008-2023 depended on internal financial situations and the general macroeconomic climate. Liquidity was generally stable, which helped the industry support short-term liabilities even in times of economic crisis. However, the levels of profitability were always low, illustrating structural financial limitations.

The financial security synthetic index (HealtFinSec), based on the TOPSIS method, had a U-shaped trend: decreased during the 2011–2016 period and then recovered afterwards, especially after the COVID-19 pandemic. This is the slow adaptation of the sector to budget constraints and external shocks.

The most notable is the high statistically confirmed correlation between macroeconomic stabilisation (MSP) and sectoral financial security. The OLS and ARMAX models show that increased macroeconomic stability, measured by GDP growth, inflation, unemployment, public deficit, and current account balance, leads to a considerable increase in financial security.

Macroeconomic conditions have a vital influence on the health sector. Financial stability is essential for policymakers to plan reforms and budgeting.

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THE IMPACT OF SUSTAINABLE DEVELOPMENT ON RETURN ON EQUITY (ROE, ROC) IN COMPANIES IN THE LOGISTICS SECTOR IN EUROPE

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Purpose: The objective of this article is to examine the impact of individual elements of the ESG strategy on the capital efficiency of logistics companies operating in Europe in the years 2017-2023.

Design/methodology/approach: The study was conducted on logistic companies from Europe. The main tool of the analysis is the OLS (Ordinary Least Squares) model with heteroscedasticity correction to examine the relationship between ROE, ROC and ESG indices and control variables.

Findings: The analysis confirms that ESG factors influence capital returns in logistics companies, with the social dimension (SCR) playing a notably positive and statistically significant role across all subsectors. This suggests that efforts toward employee welfare, ethical practices, and stakeholder engagement enhance both operational and financial performance. Conversely, the environmental index (ENV) negatively impacts profitability only in maritime transport, likely due to the high costs of ecological compliance. Corporate governance (CG) shows a negative correlation with profitability in the overall sample, implying potential misalignment with sector-specific needs. Additionally, asset size and liquidity are crucial, emphasizing the importance of integrated, balanced financial management.

Research limitations/implications: Due to the limited duration of the research sample, the conclusions drawn have a relatively short shelf life, which is one of the limitations of the analysis. Another limitation may be the use of linear models for potentially nonlinear relationships between ESG scores and financial returns.

Practical implications: The article makes a significant contribution to the literature on the financial aspects of sustainable development by presenting empirical evidence on the diverse impact of individual ESG components on capital efficiency in the logistics industry. The results of the study can provide a basis for a better understanding of the mechanisms of responsible investment and help managers, investors, and public policy makers formulate effective ESG strategies that support both environmental and social goals and the long-term profitability of companies.

Originality/value: Despite the growing importance of ESG issues, there is still a lack of clear and widely documented empirical evidence on the impact of implementing sustainability policies on key financial indicators of companies, especially in high-carbon industries such as the logistic sector. The results can be an important contribution to the debate on the role of sustainability in shaping investment decisions and financial strategies of companies.

Keywords: Sustainable development, CAPEX, profitability, ROE.

Category of the paper: Research paper.

1. Introduction

Modern enterprises operate in a dynamically changing economic, social, and regulatory environment, which increasingly forces the integration of financial goals with the principles of sustainable development. The Environmental, Social, Governance (ESG) strategy, which combines environmental, social, and corporate responsibility, is no longer perceived as a cost, but is becoming a key element in building the long-term value of an enterprise (Hoang, 2018). In this context, the importance of assessing the extent to which ESG activities translate into efficiency of capital use in companies, especially in capital-intensive sectors such as logistics, is growing (Ridwan, Alghifari, 2025).

The logistics sector, which is an important element of Europe's economic infrastructure, is currently under pressure from regulators and investors expecting responsible operating practices. Transformation toward sustainable development requires significant investment outlays, the effects of which are not immediate, but spread over time. For this reason, the evaluation of the effectiveness of implementing ESG policies should take into account not only classic profitability indicators but also capital measures such as ROE (Return on Equity) and ROC (Return on Capital), which allow for capturing the relationship between the capital employed and the achieved operational and financial results (Yoo, 2025).

The objective of this article is to examine the impact of individual elements of the ESG strategy on the capital efficiency of logistics companies operating in Europe in the years 2017-2023. Particular attention was paid to the analysis of individual dimensions – Environmental (ENV), Social (CSR) and Corporate Governance (CG) – and their impact on ROE and ROC indicators. The study is based on financial and nonfinancial data from the S&P Global Market Intelligence database, using control variables such as company size, financial liquidity, debt, and asset dynamics.

The article makes a significant contribution to the literature on the financial aspects of sustainable development by presenting empirical evidence on the diverse impact of individual ESG components on capital efficiency in the logistics industry. The results of the study can provide a basis for a better understanding of the mechanisms of responsible investment and help managers, investors, and public policy makers formulate effective ESG strategies that support both environmental and social goals and the long-term profitability of companies.

2. The Impact of Sustainable Development Strategies on Capital Efficiency: The Role of ROE and ROC in Evaluating ESG Implementation - literature review

Sustainable development of an enterprise, defined as a strategy that combines economic goals with social and environmental responsibility, has a significant impact on the way invested capital is used and its efficiency (Edwards, 2021). Modern companies, which implement environmental, social and governance policies, increasingly treat sustainable development not as a cost, but as an investment in the long-term value of the company (Lassala et al., 2021).

The impact of sustainable development on invested capital manifests itself primarily in changes in the structure of resource allocation. Logistics companies investing in low-emission technologies, energy efficiency, responsible supply chains, or good management practices often invest capital in projects whose return is not immediate but appears over a period of several years (Bhattacharjee et al., 2024). Such a strategy requires appropriate capital management, both own and external, in order to maintain financial liquidity and operational stability in the transformation phase (Le et al., 2024; Fallah Shayan et al., 2022).

From the point of view of capital owners, i.e. investors and shareholders, sustainable development can significantly increase the attractiveness of the company, especially in conditions of growing regulatory pressure and social awareness. Investors increasingly expect not only rates of return but also compliance of the company's activities with social and environmental values (Gniadkowska-Szymańska et al., 2024b; Park et al., 2022). Companies with high ESG standards gain easier access to capital, more favourable financing conditions, and a higher market valuation (Yoo, 2025). As a result, a well-implemented sustainable development strategy can increase the efficiency of the use of invested capital, which translates into higher financial indicators such as ROE (Return on Equity) and ROC (Return on Capital) (Chen et al., 2023; Sanga, 2024).

However, the lack of a coherent ESG policy or its superficial implementation can lead to reputational risks, regulatory penalties, and increased operating and financial costs. The changing legal environment and social pressure mean that capital invested in companies that do not comply with the principles of sustainable development is more exposed to the risk of loss of value (Sadowski et al., 2024; Gniadkowska-Szymańska et al., 2024a; Cheska et al., 2022).

In the context of analysing the impact of sustainable development strategies (ESG) on the financial results of companies, capital efficiency indicators such as ROE (Return on Equity) and ROC (Return on Capital) are of particular importance (Plaskova, 2022). Both of these measures allow us to assess how effectively a company uses its available capital – equity and total – to generate profits, which is of significant importance in the context of implementing costly but strategically important ESG initiatives (Chang et al., 2024; Khatami et al., 2025).

ROE, or return on equity, illustrates the effectiveness of using the funds entrusted to the company by owners and shareholders. A high ROE value in the context of implementing an ESG strategy may indicate that activities in the field of social responsibility, environmental protection and corporate governance not only do not burden the company, but actually contribute to increasing its profitability and increasing shareholder value (Yustrianthe et al., 2021; Ningrum, 2023). Investors, especially those interested in ESG criteria, often treat ROE as one of the main indicators of management efficiency, which emphasises its importance in the context of assessing the success of a sustainable development strategy (Lin et al., 2025).

However, it should be noted that a low ROE value in companies implementing ESG does not necessarily indicate the ineffectiveness of these activities. It may result from the high investment outlays incurred in the initial phase of transformation, the positive financial effects of which will only be visible in the longer term. Therefore, a complementary analysis of the second indicator, the ROC, is necessary (Damodaran, 2007).

Return on Capital measures the return on total capital, i.e. both equity and debt. This is particularly important in capital-intensive sectors such as logistics, where a large part of the activity is financed by debt or leasing (Banerjee, Deb, 2023; Ichsani et al., 2015). In this context, ROC allows for a more objective assessment of the impact of ESG activities on the operational efficiency of the company, regardless of its financing structure (Lutfiani, Hidayah, 2022). If pro-ecological, social, and corporate governance activities lead to an increase in ROC, it means that they bring real benefits in the form of higher operating profitability. In turn, a low ROC, especially in the initial phase of the implementation of ESG, may indicate the need for a patient investment approach and the potential need for external support, both financial and regulatory (Jun et al., 2022). It is worth noting that both ROE and ROC provide information not only on the current state but also on the long-term effects of strategic decisions made by the company (Damodaran, 2007). Their simultaneous analysis allows for a more comprehensive assessment of the impact of ESG policy on financial efficiency, on the one hand from the point of view of capital owners and on the other from the perspective of total resources engaged in operational activity. In the context of ESG, this is particularly important as many initiatives require balanced development, the return of which occurs only after several years (Iazzolino et al., 2023; Lu et al., 2022). The ROE and ROC indicators play an important role in analysing the effectiveness of implementing ESG policies (Shmelev et al., 2025). They allow us to assess whether a company can transform investments in sustainable development into real financial value (Bolek et al., 2025). Their interpretation, taking into account both the short- and long-term perspective, is of key importance for managers, investors, and decision makers responsible for shaping pro-ecological and socially responsible strategies (Rydzewska, 2023, Bolek et al., 2025; Lutfiani, Hidayah, 2022).

3. Research methodology

The study was carried out in a group of logistics companies operating in Europe. The period from 2017 to 2023 was adopted for the study, because these companies reported their ESG activities only from 2017.

The study used annual data. All data used in the study came from the S&P Global Market Intelligence database. Prices were adjusted for changes in equity, such as subscription rights, dividends, and splits. The following data was used for the calculations:

- Pref - measured using ROC and ROE.
- ESG Index - The S&P Global Market Intelligence ESG Index includes all disclosures regarding environmental factors, social and governance indicators of the company (i), in the period (t).
- ENV index - S&P Global Market Intelligence EVN Index, which measures the disclosure of energy consumption, waste, pollution, protection of natural resources and treatment of animals in company (i) in period (t).
- CRS Index – S&P Global Market Intelligence CSR Index measures the disclosure of business relationships, donations, volunteering, health and safety of employees of company (i), in period (t).
- CG Index – S&P Global Market Intelligence CG Index measures disclosure of the corporate governance code of company (i) in period (t).
- TA – company size; a control variable measured by the total assets of company (i) in period (t).
- Lev – financial leverage; a control variable measured as the ratio of total debt to total assets of company (i) in period (t) (Akbar et al., 2025).
- Turn(TA) – asset turnover, measured by net sales as a percentage of total assets.
- Gr(TA) – asset growth, measured by annual change in total assets.
- CR – current liquidity ratio.

Return on Capital (ROC), also known as Return On Invested Capital (ROIC), or Return On Capital Employed (ROCE), is a financial ratio that measures a company's profitability relative to the amount of capital invested. It indicates how effectively a company uses its capital to generate profits. This ratio is calculated by dividing Net Operating Income After Tax (NOPAT) by the average book value of Invested Capital (IC). Since financial theory states that the value of an investment is determined by both the amount and the risk of expected cash flows to the investor, ROIC and its relationship to the Weighted Average Cost of Capital (WACC). The cost of capital is the return expected from investors to bear the risk that the projected cash flows of an investment deviate from expectations. It is said that for investments in which future cash flows are progressively less certain, rational investors require progressively higher rates of return as compensation for bearing a higher degree of risk. In corporate finance, WACC is

a common measure of the minimum expected weighted average return of all investors in a company, given the riskiness of its future cash flows (Damodaran, 2007; Luhtaniemi, 2023).

ROE is one of the most important indicators in ratio analysis. The higher the value of this indicator, the more favourable the company situation. ROE stands for Return on Equity, or Return on Equity. This is a profitability indicator that indicates how much profit the company managed to generate from the contributed equity (Serzante, Stankevych, 2024).

The return-on-equity indicator provides valuable information to shareholders. When calculating ROE, the profit for a given period is calculated relative to the state of equity at the beginning of a given period. This indicator is created by dividing net profit by equity expressed as a percentage (Mudzakar, Wardanny, 2021).

High values of the indicator and an increase in its level over time are positively assessed (this indicates a high or increasing return on equity). Low values of the indicator and a decrease in its level over time are negatively assessed (this indicates a low or decreasing return on equity). It is worth knowing that the ROE indicator can have negative values. This can occur when the company generated a loss in a given period, i.e. did not obtain an accounting surplus of revenues over costs. Negative values indicate an unfavourable company situation. It should also be remembered that ROE is not a constant value. This indicator is highly dependent on the phase of the cycle in which the capital market is (Heikal et al., 2014). The most favourable signal for shareholders is a situation where a company achieves a high ROE indicator and is above the industry average. This is a proof that the company effectively manages its capital. There may also be a situation where the ROE indicator is even three times higher than the industry average. It is worth analysing the company's financial results in such cases (Ichsani et al., 2015). Perhaps this only means that the company is doing surprisingly well compared to the competition. But such a situation may also be a proof that the company has excessive debt. This can significantly increase ROE, because equity is assets minus debt. Therefore, the more a company becomes in debt, the lower the equity, which may affect ROE (Damodaran, 2007).

The table 1 presents the data data statistics for the analysed used in the study.

Table 1.

Summary statistics of all variables

	Mean	Median	Max	Min	S.D.
<i>Current Ratio (x)</i>	1.154	1.05	3.41	0.38	0.50
<i>ROC</i>	8.470	5.93	60.43	0.05	8.52
<i>ROE</i>	43.805	13.71	917.95	0.03	109.31
<i>Turn(TA)</i>	0.791	0.70	2.05	0.07	0.50
<i>TA</i>	11162693.358	2475549.23	93680000.00	285640.38	19732131.28
<i>Lev</i>	62.537	61.44	109.15	18.40	20.64
<i>ENV Index</i>	46.711	43.00	95.00	10.00	24.06
<i>SCR Index</i>	42.361	39.50	88.00	9.00	21.15
<i>CG Index</i>	43.720	42.00	81.00	0.00	19.21

Source: own study.

The study decided to test the following research question:

1. The ROC indicator is influenced by variables that are components of the ESG index (ENV index, SCR index, CG index).
2. The ROE indicator is influenced by variables that are components of the ESG index (ENV Index, SCR Index, CG Index).

The analysis related to the preferences of companies regarding the impact on ROC and ROE was presented in the form of parameter estimation of OLS models with heteroscedacity correction and panel models. Cross-sectional OLS models were used, in which the results related to the size of the company measured by assets constitute a logarithmic variable, which is explained by the nonlinearity of this indicator in relation to the explained variables. The study used cross-sectional regression analysis and panel data. Tests for the presence of fixed and random effects were also conducted (redundant fixed effects - Wald test, random effects - Breusch-Pagan test).

The model for the total sample is presented in Equation 1.

$$Pref_{it} = \alpha_0 + \alpha_1 EVN_{it} + \alpha_2 CSR_{it} + \alpha_3 CG_{it} + \alpha_4 \ln(TA)_{it} + \alpha_5 Gr(TA)_{it} + \alpha_6 Turn(TA)_{it} + \alpha_7 Lev_{it} + \varepsilon_{it} \quad (1)$$

The independent variables were not collinear, since most of the VIF values were <5.

4. Research results

After conducting a descriptive analysis of the variables and testing the assumptions of the regression analysis, we use regression analysis to examine the components of the impact of the ESG index [CG, EVN, and CSR (independent variables)] on the company's ROC or ROE [dependent variables]. First, using an OLS model with heteroscedasticity correction, the relationship between ROC and ROE and CG, EVN and CSR indices and control variables was examined using equation 1. The study was carried out for all logistics companies regardless of their business profile and divided into companies dealing with air, sea, and land logistics (rail and road).

The RESET test was also used to analyse the model specification, which showed the correctness of the applied model (p value > 0.05). The results obtained from the RESET test show that the specification of the variables in the model is correct. The results of this estimate are presented in Table 2.

Table 2.*Estimation of model parameters from equation (1) using the OLS method*

	ROC	ROE
All		
const	-0.635476	69.8962
Lev	-0.00556664	0.928123 ***
lnAT	0.164231	-10.2649 ***
Turn(AT)	6.243 ***	12.3985
CR	9.59037 ***	19.8014 **
Gr(TA)	0.0722589 **	0.305256 ***
ENV Index	-0.123606	0.524586
SCR Index	0.294098 ***	1.69407 ***
CG Index	-0.360219 **	-1.76754 ***
R2	80%	73%
AIR		
const	-16.7079	14.7261
Lev	0.117394 *	1.87414 ***
lnAT	0.624197	-11.3392 **
Turn(AT)	6.35266 **	58.256 **
CR	3.5422	-17.5605
Gr(TA)	-0.0149999	0.215857 *
ENV Index	0.232465	-0.711730
SCR Index	0.347229 ***	0.207926*
CG Index	-0.0911948	-0.740656 *
R2	78%	85%
MARINE		
const	32.391 **	27.9534
Lev	-0.0931756	0.316496
lnAT	-2.41721 *	-6.86077 **
Turn(AT)	-2.63521	-6.08623
CR	8.6497 ***	22.2357 ***
Gr(TA)	0.0845535 **	0.325394 **
ENV Index	-0.194068 *	-0.668233 ***
SCR Index	0.752434 ***	2.59955 ***
CG Index	-0.224103	-0.102839*
R2	90%	89%
Ground		
const	47.4745	804.326 *
Lev	0.200228	-0.0792611
lnAT	-3.76162	-61.5458 *
Turn(AT)	-3.00489	33.0815
CR	-24.2072	46.2461
Gr(TA)	0.0913333	0.0505877
ENV Index	-0.0691649	1.44367
SCR Index	0.97535 **	3.37535 *
CG Index	-0.134584	-1.80877 *
R2	99%	98%

Note: */**/** Indicators are significant at 10% / 5% / 1% respectively.

Source: own study.

The regression analysis performed showed that among the components of the ESG index, the SCR (Social Corporate Responsibility) variable has a positive and statistically significant impact on the ROC (Return on Capital) indicator, both in the case of a collective analysis of all logistics companies, as well as in the analysis conducted by specialisation (land, sea, air transport).

In the case of the ENV (Environmental Index) variable, a significant but small negative impact on ROC was observed only in the group of companies specialising in sea transport. In turn, CG (Corporate Governance) shows a negative correlation with ROC, but the statistical significance of this relationship is maintained only in the general analysis (for the entire sample) and disappears after breaking the data into industry groups.

When analysing control variables, the greatest impact on ROC is exerted by current liquidity (CR) ratios and the annual growth of total assets. The remaining control variables do not show a significant impact on the formation of this indicator in the companies surveyed.

Similar relationships were observed in the case of the impact of ESG on the ROE (Return on Equity) indicator. The SCR variable also has a positive and significant impact here, regardless of the logistics industry. However, the CG variable has a statistically significant but negative impact on ROE in the general analysis, but it is not significant from an industry perspective. The ENV variable has a negative and significant impact only on the ROE indicator of companies involved in sea transport.

In the case of control variables, in the analysis of the entire sample and in the groups of sea and air companies, all the variables included have a statistically significant impact on ROE. On the other hand, in the case of land transport (rail and road), only the variable (natural logarithm of the value of assets) shows a significant impact on ROE, while the remaining variables did not reach the level of statistical significance.

The tests used - the Wald test for fixed effects and the Breusch-Pagan test for random effects - allowed us to determine the best panel regression model. Models with random effects did not produce significant results, so models with fixed effects were adopted for further analysis, the results of which were consistent with previous analyses.

5. Discussion and Conclusions

The observed positive and statistically significant relationships between the social dimension of ESG (SCR) and return on capital indicators (ROE and ROC) support the thesis that corporate social responsibility can be a source of competitive advantage and increase the operational efficiency of enterprises.

These results are consistent with the growing trend of financial literature that treats the social component of ESG as a value-creating factor, not just a cost. At the same time, the negative impact of the environmental component (ENV) in the maritime sector emphasizes the need for further research on the nonlinearity and temporal nature of returns on pro-ecological investments, which indicates the potential of using the ESG investment life cycle theory and dynamic models (Cheska et al., 2022).

The negative correlation for the corporate governance component (CG) may suggest the limitations of agency theory in sectors with high operational complexity, which is an important contribution to the discussion on the contextual effectiveness of supervision mechanisms.

In terms of control variables, a significant impact on profitability was demonstrated for the current liquidity ratio (CR) and the value of assets (lnAT). This indicates the need to pursue a balanced financial policy in which the ESG strategy should go hand in hand with responsible management of assets and liabilities (Banerjee, Deb, 2023).

From a managerial and investor perspective, the results suggest that the greatest potential for improving capital efficiency in the logistics sector lies in social investments – in human capital, stakeholder relations and organizational culture. Companies should prioritize SCR strategies as an element enhancing shareholder value. At the same time, the results indicate the need for a realistic assessment of the impact of environmental initiatives, especially in subsectors requiring high capital expenditures, such as maritime transport. When implementing environmental strategies, companies should plan for a longer payback horizon and consider the use of regulatory support and external financing mechanisms (e.g. green bonds). In terms of corporate governance, companies should adapt management structures to the specifics of the business, avoiding excessive formalization, which may limit operational flexibility.

To deepen the understanding of the relationship between ESG and financial performance, it would be advisable to use more advanced econometric models that allow for the identification of causality (e.g., dynamic effects panel models, GMM models). Moreover, the inclusion of a qualitative approach, e.g., case studies, interviews with ESG managers, would allow for capturing the organizational and cultural context that influences the effectiveness of implemented strategies. Integration of quantitative results with ESG finance theory, such as the theory of socially responsible investing, stakeholder theory, or long-term value creation theory, could significantly strengthen the theoretical contribution of the manuscript.

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UNLOCKING COMPETITIVE ADVANTAGE: EXPLORING THE INFLUENCE OF ORGANIZATIONAL UNLEARNING

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Purpose: The purpose of this paper is to examine the role of organizational unlearning in shaping competitive advantage, with particular attention to its potential mediating mechanisms. The authors aim to expand the traditional perspective, which predominantly emphasizes organizational learning, by exploring how unlearning enables organizations to adapt their knowledge and practices in pursuit of competitive advantage.

Design/methodology/approach: The study is based on a quantitative analysis of data collected from 363 randomly selected Polish enterprises. Structural equation modeling (SEM) was used to test the relationships between unlearning, creativity, innovation, and competitive advantage. Validated measurement scales were employed, and firm age and size were included as control variables.

Findings: Our findings highlight that while organizational unlearning does not directly impact competitive advantage, its effect becomes significant when mediated by organizational creativity. Moreover, our study underscores that although organizational creativity fosters innovation, innovation alone does not directly translate into competitive advantage. These findings challenge conventional assumptions about the linear relationship between unlearning, innovation, and firm performance, suggesting that creativity, rather than innovation, serves as a mediator between unlearning and competitiveness.

Research limitations/implications: A key limitation of the study lies in the potential bias resulting from the use of a single data source, as well as the focus on competitive advantage rather than financial metrics. Future research should consider longitudinal and comparative approaches that integrate both qualitative and quantitative perspectives on unlearning across diverse organizational contexts.

Practical implications: The study suggests that cultivating a culture of strategic unlearning – through the removal of outdated practices and support for organizational creativity – may enhance organizational agility and long-term performance. Encouraging collaboration, communication, and experimentation could help strengthen organizations' ability to build and sustain competitive advantage.

Originality/value: Our paper contributes to knowledge management and organizational change literature by highlighting the strategic importance of creativity in unlearning-driven competitive advantage. It offers a novel empirical perspective that refines existing assumptions about the role of innovation and creativity in linking unlearning to organizational outcomes.

Keywords: organizational unlearning, organizational creativity, innovation, competitive advantage.

Category of the paper: research paper.

1. Introduction

Organizations today contend with the challenge of adapting to a volatile environment, seeking to foster innovation by changing their operational approaches. To ensure their continued success, it's crucial for these organizations to reconsider their traditional methods. This necessitates a deeper understanding of inherent dynamics and complex relationships, particularly when viewed through the lens of organizational unlearning—a critical factor in adapting to environmental changes and promoting creativity and innovation to enhance competitive advantage. Scholars have long signaled the concept of a learning organization as a key avenue for gaining and maintaining a competitive edge in dynamic and turbulent environments, fostering adaptability (Ferreira, Coelho, Moutinho, 2020; Hamel, Prahalad, 1993). However, simply having the characteristics of a learning organization does not guarantee survival or competitiveness (Ghasemaghaei, Calic, 2020).

Organizations should consciously break away from established patterns and modes of thinking, engaging in a process termed "organizational unlearning" in the literature. Essentially, this involves organizations 'learning to forget' (Hamel, Prahalad, 1994; Lyu et al., 2020), enabling them to swiftly adapt to the ever-changing environment. However, unlearning should not be perceived as a passive erasure of knowledge but rather as a proactive and strategic process that enables the organization to question outdated assumptions and create space for new approaches (Cegarra-Navarro, Moya, 2005; Cohen, Levinthal, 1990; Grisold, Kaiser, Hafner, 2017).

The literature establishes that the ability to unlearn contributes to the competitive advantage of a firm (Martignoni, Keil, 2021). However, the specifics of how and when this relationship occurs remain relatively unexplored. Moreover, unlearning seems to be crucial for adapting to the changing environment and supporting innovation (Bettis, Prahalad, 1995; Nystrom, Starbuck, 2012; Tsang, Zahra, 2008).

Organizational unlearning plays a vital role in promoting organizational learning, enhancing performance, and overcoming cognitive and structural barriers (Tsang, Zahra, 2008). Moreover, by encouraging the exploration of new perspectives, unlearning contributes to the dynamic nature of organizational systems, allowing them to remain agile and responsive to emerging challenges (Bettis, Prahalad, 1995; Nystrom, Starbuck, 2012). Unlearning is particularly crucial for large corporations aiming to develop disruptive innovations, involving the overcoming of inhibiting factors such as the inability to unlearn obsolete mental models (Assink, 2006). In the context of absorptive capacity and innovativeness, organizational unlearning is

highlighted as a crucial determinant, emphasizing the need for companies to unlearn established beliefs and methods to be receptive to new information (Cepeda-Carrion et al., 2012).

Leal-Rodríguez et al. (2014) extend the discussion by exploring the relationship between organizational unlearning, innovation outcomes, and business performance. This relationship, however, does not occur in a vacuum. Organizational creativity seems to play an important role in explaining both innovation (Klammer, Gueldenberg, 2020) and firm performance (Ferreira, Coelho, Moutinho, 2020). In essence, fostering unlearning can lead to enhanced innovation, which, in turn, positively affects overall firm performance.

Hence, excessive adherence to established rules and procedures can impede an organization's adaptability. The accumulation of knowledge at the organizational level, while valuable, can paradoxically hinder creative processes and innovation—essential elements for gaining a competitive edge (Clark, 2014; Easterby-Smith, 1997; Hedberg, 1981). Therefore, the primary goal of this article is to explore the relationship between organizational unlearning and competitive advantage, with a specific focus on the role of creativity and innovation within organizations. Understanding this relationship is pivotal, as the ability to unlearn, shed outdated practices, and embrace new ideas often sets successful organizations apart (Martignoni & Keil, 2021). The capacity to adjust and revamp strategies in response to changing dynamics can pave the way for sustained success and a lasting competitive advantage. This article seeks to delve into these aspects to shed light on the transformative potential of organizational unlearning and the role of creativity and innovation in today's organizational landscape.

2. Theoretical foundations of organizational unlearning and its role in building competitive advantage

2.1. Uncovering the links between organizational unlearning and competitive advantage

In the ever-evolving landscape of organizational dynamics, organizational unlearning emerges as crucial competency (Zhao & Wang, 2020). It is not only vital for organizations to possess the capability to adapt and alter established methodologies and procedures (Lorenzen, 2001) but also important to conduct a thorough reassessment of ingrained habits and routines that have become obsolete (Grant, 1991). This dynamic process encompasses shedding outdated knowledge, challenging conventional wisdom, and fostering a culture of perpetual innovation. It transcends mere adaptation, demanding a fundamental reevaluation of ingrained practices and the willingness to 'unlearn' in order to pave new pathways forward.

Extensive studies highlight the profound impact of organizational unlearning on a firm's competitive advantage. Multiple perspectives presented in the literature support this hypothesis. For instance, Griffith and Hoppner (2013) propose a model emphasizing soft skills, such as

tacit knowledge, learning, unlearning, and flexibility, as drivers for global marketing managers to make tactical adaptations, thereby enhancing a firm's global marketing strategy. This underscores the integral role of an organization's ability to unlearn and adapt in maintaining its competitive position.

Study conducted by Tsang and Zahra (2008) emphasizes the importance of organizational unlearning in successfully adapting to environmental changes and positively impacting company performance. This aligns with the notion that firms need to unlearn obsolete mental models to foster disruptive innovation capability, as discussed in Assink's conceptual model (2006). Azmi's work (2008) highlights the significance of the learn-unlearn-relearn model in navigating the dynamic business environment, stressing the necessity for organizations to continuously rejuvenate and suggesting that strategic advantage hinges on the unlearning of outdated practices.

Similarly, Wensley and Navarro (2015) propose the implementation of an unlearning context to counteract knowledge degradation in the hospitality sector, implying that unlearning is not only about eliminating obsolete routines but also about creating an environment conducive to acquiring new knowledge. Furthermore, research by Zhang and Zhu (2021) explores the relationship between social media strategic capability and disruptive innovation, highlighting the mediating role of organizational unlearning, indicating that organizations harnessing social media for innovation need to cultivate an environment conducive to unlearning old practices.

In the socio-cognitive framework proposed by Akgün, Lynn, and Byrne (2003), organizational learning is explored from a social cognition perspective, emphasizing the reciprocal interactions of various processes, including unlearning. This integration of unlearning into the organizational learning process suggests its significance in gaining a competitive advantage through continuous adaptation and improvement (Akgün, Lynn, & Byrne, 2003). Lei, Slocum, and Pitts (1999) further support this notion by emphasizing the power of unlearning in designing organizations for competitive advantage. Akgün, Lynn, and Byrne's (2006) empirical investigation into new product development teams underscores the importance of unlearning in work groups, particularly in the context of coping with environmental turbulence, suggesting that effective unlearning is crucial for organizations to adapt successfully to changing market conditions and gain a competitive edge.

Baker and Sinkula (2014) challenge the idea that strong market orientation alone ensures competitive advantage, emphasizing the role of organizational unlearning in navigating market dynamics. Similarly, Navarro and Moya (2005) highlight unlearning as essential for dismantling obsolete knowledge structures, making space for new insights. However, they note that success can impede this transition, as preserving existing structures may hinder adaptation and long-term competitiveness. Research underscores that unlearning enhances adaptability and performance by replacing outdated knowledge with fresh perspectives, ensuring competitiveness in dynamic markets (Nystrom, 2015). This process goes beyond simple

adaptation; it represents a deliberate break from the past, fostering innovation and a culture of continuous improvement.

Starbuck's research (2017) delves into the dynamics of organizational adaptation, learning, and unlearning, particularly in the context of crises. While not explicitly addressing competitive advantage, the paper emphasizes that organizations responding slowly or inadequately to crises may enter a stage of unlearning that is demoralizing and harmful. This suggests that the ability to effectively respond to external challenges and engage in unlearning processes is crucial for organizational survival and, by extension, competitive longevity.

Organizational unlearning plays an essential role in addressing challenges, fostering innovation, and facilitating adaptation to change, all of which contribute to a firm's competitive position. Becker's (2008) case study research provides insights into the concept of unlearning, highlighting inhibitors and enablers of the unlearning process. The model that emerges from the data emphasizes the importance of unlearning for sustainable change and innovation. This suggests that organizations that actively engage in unlearning may gain a competitive advantage through their ability to adapt and innovate. Organizational unlearning can also become a means for inducing multifaceted learning, enabling companies to develop and exploit entrepreneurial capabilities. The emphasis on unlearning suggests a positive relationship between unlearning and the development of competitive advantage (Zahra et al., 2011). In summary, the exploration above leads us to propose the following hypothesis:

H1: Organizational unlearning is positively related to firm's competitive advantage.

2.2. Organizational creativity as a mediator in the relationship between OU and competitive advantage

In the highly competitive contemporary business environment, innovation and creativity are fundamental to addressing competitive challenges with agility and responsiveness. However, fostering these capabilities often requires a preceding process of organizational unlearning, wherein outdated behaviors, practices, or routines that no longer align with present realities are abandoned (Leal-Rodríguez, Eldridge, Roldán, Leal-Millán & Ortega-Gutiérrez, 2015). As underscored by Cepeda- Carrión, Cegarra- Navarro & Leal- Millán (2012), the creation of an environment conducive to creativity necessitates a deliberate revision or replacement of existing organizational knowledge. This action becomes imperative to enable the generation of new and useful ideas. This transformative process parallels the act of “clearing a canvas”, providing a blank space on which new, innovative strokes can be painted, thereby propelling organizational success and adaptability within the dynamic and competitive business environment.

A creative organization is not only capable of innovation but also open to experimentation, as emphasized by Amabile (1998). Lorenzen (2001) further highlights that this willingness to experiment strengthens organizational unlearning. The link between creativity and unlearning

underscores the need for organizations to adopt new ideas while actively discarding outdated concepts, routines, and methods that hinder innovation. In this way, unlearning becomes essential to an organization's creative process, enabling the continuous renewal of perspectives and strategies.

Scholars posit that organizational unlearning is essential for fostering creativity and generating new ideas (Martins, Martins & Pereira, 2017). It also plays a key role in developing and implementing innovations (Lorenzen, 2001), or giving organizations a competitive edge (Mezias, Grinyer, Guth, 2001). In times of uncertainty and instability, it becomes a crucial defense mechanism, providing firms with the resilience and adaptability needed not only to survive but to thrive in a constantly changing business environment. By fostering creativity, organizations enhance their ability to identify and seize new opportunities while optimizing existing ones. This dual approach strengthens their competitive advantage in dynamic markets (Matzler et al., 2013). What it also worth to notice, highly creative organizations often exhibit greater structural flexibility, rendering them more adept at adapting to the environment. This enhanced adaptability furnishes them with a strategic advantage, enabling the adept exploitation of opportunities and, in turn, surpassing their competitors (Damanpour & Gopalakrishnan, 2001).

Organizations characterized by creativity demonstrate an increased likelihood of not only enduring but thriving within environments marked by volatility and uncertainty. Intentionally letting go of entrenched beliefs and obsolete practices, organizations create space for new ideas and approaches to emerge. Furthermore, unlearning facilitates the dismantling of rigid cognitive frameworks, thereby promoting a culture that supports continuous learning and creative problem-solving (Grisold, Klammer & Kragulj, 2020). Therefore, rather than viewing unlearning as a regression, it should be recognized as a proactive strategy that paves the way for organizational renewal and creative advancement. Consequently, it becomes a compelling pursuit to scrutinize whether constructs such as organizational creativity serves as a mediating mechanism in the nexus between organizational unlearning and competitive advantage.

To sum up all the above-mentioned, it can be argued that organizational creativity serves as a catalyst for the competitive advantage of the company (Anderson, Potočnik & Zhou, 2014). Additionally, organizational creativity, as a process of deliberately criticizing and updating beliefs to propose novel and useful organizational solutions (Choi, Ingram & Han, 2023), relies on the organizational ability to shed outdated concepts, solutions, routines, or actions (Klammer & Gueldenberg, 2020). Thus, it might be argued that organizational creativity plays a vital role in explaining the complicated relationship between organizational unlearning and competitive advantage.

On the basis of all the above-mentioned considerations, we propose the following hypotheses:

H2: Organizational creativity is positively related to firms' competitive advantage;

H3: Organizational unlearning is positively related to organizational creativity;

H4: Organizational creativity mediates the relationship between organizational unlearning and competitive advantage.

Organizational creativity emerges as a pivotal mechanism linking unlearning to competitive advantage. By fostering creativity, organizations gain the ability to reframe obsolete routines, enabling adaptive and innovative strategies. This underlines creativity's essential mediating role in translating unlearning into tangible competitive outcomes.

2.3. Contextualizing the relationships between organizational unlearning, organizational creativity on competitive advantage: The role of innovation

Organizational creativity, perceived as processes leading to new and useful organizational ideas, although related to competitive advantage, does not directly lead to performance and, thus, does not create a competitive advantage in a direct way. These ideas must be transformed into valuable and novel products and services, and that is where innovation comes into play. These new products, services, and methods help to create value for customers, which is necessary for organizations to grow and compete effectively. Thus, enriching our argument, innovation, and innovation output, in particular, defined as created and introduced new and valuable solutions, products, and processes, serve as a catalyst for creating sustainable competitive advantage for the company.

Innovation in organizations is a multifaceted process influenced by various factors, and a key contributor to this dynamic is organizational creativity (Amabile, 1988; Csikszentmihalyi, 1997). Research conducted by various scholars in the fields of management and innovation suggests a strong correlation between creativity and innovation in organizations (Kim, Oja, & Anagnostopoulos, 2023; Fetrati, Hansen, & Akhavan, 2022). Researchers such as Amabile (1996) and Csikszentmihalyi & Csikszentmihalyi (2014) emphasize the relationship between creativity and innovation, providing a comprehensive framework for understanding how creative processes contribute to organizational innovation.

Ahlstrom (2010) argues that the primary goal of business is to introduce new and innovative products that drive growth and provide benefits to an increasingly broader audience. Innovativeness requires new ideas, meaning it must be preceded by creativity. In this sense, creativity differs from innovative activity, which focuses not so much on generating creative ideas but on implementing them in practice (Klijn & Tomic, 2010; Rampa, & Agogu  , 2021). Creativity is predominantly described as the process of generating novel and valuable ideas (Amabile, 1996), while innovation is recognized as the effective implementation of these ideas (Amabile, 1988; Fetrati, & Nielsen, 2018). From the standpoint of economic activity, creativity itself has limited value unless it results in the implementation of new products, services, or processes.

In light of this evidence, we could posit that enhanced creativity can significantly impact the organization's ability to innovate. Creativity serves as the primary driver that leads to the generation of new ideas, which, under the right conditions, can evolve into fully-fledged

innovations. Effectively managing creativity within an organization may, therefore, be a key factor influencing its ability to adapt, compete, and sustain long-term development.

Summing up all the previously raised arguments, it can be reasoned that innovations play a pivotal role in fostering a competitive advantage, enabling organizations to compete effectively in highly dynamic environment (Cao et al., 2022). Also, without a doubt, organizational innovation strongly relies on organizational creativity (Damadzic et al., 2022), as creativity entails necessary processes related to proposing novel and valuable ideas. As such, for the introduction of new organizational solutions, frequently abandoning old practices, processes, or products is necessary (Duan et al., 2023), thus mindful unlearning facilitates innovativeness in organizations. Recent studies have highlighted the positive relationship between organizational unlearning and product innovation performance, emphasizing that unlearning outdated knowledge structures can lead to improved innovation outcomes (Wang et al., 2022). We imply that innovations transpose new and useful ideas into new products and services which actively improve the market position of the organization, thus serving as a catalyst for growing the competitive advantage of a company (Tuan, 2023). Finally, the ability to mindful organizational unlearning comprises a starting point for questioning the old and fostering the new. This leads us to proposing the following research hypotheses:

H5: Innovation is positively related to competitive advantage.

H6: Organizational unlearning is positively related to innovation.

H7: Organizational creativity is positively related to innovation.

H8: Innovation mediates the relationship between organizational unlearning and competitive advantage.

H9: Organizational creativity and innovation mediate the relationship between organizational unlearning and competitive advantage.

Innovation alone does not ensure competitive advantage unless driven by creativity and supported by unlearning processes. Although innovation operationalizes new ideas, its competitive value is contingent upon the strategic interplay of organizational creativity and the willingness to abandon outdated knowledge.

2.4. Moderating role of environmental dynamism in the relationship between organizational unlearning and competitive advantage

Environmental dynamism, characterized by rapid changes in market conditions, requires organizations to constantly adapt their strategies to stay ahead (Jansen, Van Den Bosch, Volberda, 2006). It refers to the degree of change and uncertainty in the external environment of a business, including factors such as market conditions, technological advancements, regulatory changes, and competitive forces (Sirmon, Hitt, Ireland, 2007).

The direct relationship between environmental dynamism and competitive advantage can be challenging to capture definitively because it is typically a complex process, and the impact of one factor on the other may be mediated by various mechanisms (Li, Dai, Cui, 2020). Moreover, usually, environmental dynamism is perceived as a factor moderating relationships in organizational settings, as it captures the conditions in which certain links between organizational phenomena occur (Mikalef et al., 2019).

In this vein, understanding how environmental dynamism moderates the relationship between organizational unlearning and competitive advantage is crucial for organizations seeking to navigate and succeed in rapidly changing environment. As Zhang and Zhu (2021) point out, environmental dynamism serves as a moderator of the relationship between organizational unlearning and disruptive innovation, which may lead to competitive advantage. Similarly, Wang et al. (2022) emphasize the effect of environmental dynamism on the relationship between organizational unlearning and organizational performance measures – namely, product innovation performance. Also, Chen, Coviello, and Ranweera (2021) signal the influence of external and internal organizational dynamism on the relationship between network capabilities, generative NPD learning, perceived as the ability to unlearn and engage in exploratory new learning, and firms' capacity for innovation. On the basis of the above-stated considerations, we posit two research hypotheses:

H10: Environmental dynamism is related to firms' competitive advantage.

H11: Environmental dynamism moderates the relationship between organizational unlearning and firms' competitive advantage.

While environmental dynamism was hypothesized to influence the link between unlearning and competitive advantage, findings suggest this relationship remains largely unaffected. This reinforces the view that unlearning is an internally driven capability, not necessarily dependent on external turbulence.

Summing up the above considerations, a number of questions were asked about the interrelationships between organizational unlearning, organizational creativity, innovation, and the competitiveness of enterprises in the conditions of a dynamically changing environment. The proposed theoretical model (see Figure 1) provides a foundation for empirical research, illustrating how these elements interact to shape an organization's ability to gain a competitive advantage amid uncertainty and change.

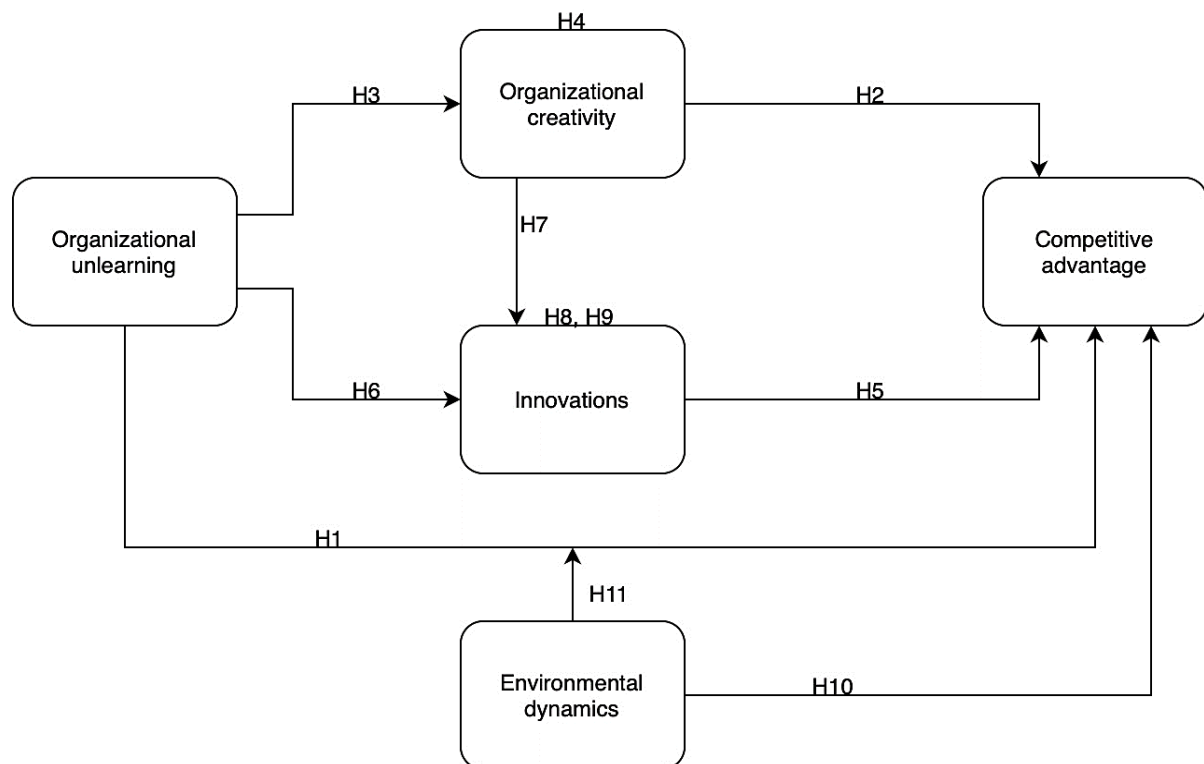


Figure 1. Hypothesized relationships between organizational unlearning and competitive advantage in the context of organizational creativity, innovation, and environmental dynamism.

Source: own elaboration.

3. Methodology

3.1. Sample

To test the proposed hypotheses, we conducted quantitative empirical research employing data collected from a sample of 363 randomly selected Polish enterprises. Data collection took place in the autumn of 2022. Upon examination of the research sample, it is noteworthy that a majority of the surveyed enterprises exhibited operations primarily within a local or national scope. The surveyed entities were primarily engaged in service provision, with a considerable presence of entities demonstrating a mixed and commercial profile. The average organizational lifespan among the surveyed firms stood at 18.6 years, with a median company size of 17 employees. A comprehensive summary of the sample's characteristics is provided in Table 1.

Table 1.*Profile and size of companies included in the final sample*

The scope of the company's operation	The profile of the company's activity		
Local	107	Commercial	66
Regional	84	Service	157
National	122	Production	52
International	39	Mixed	81
Global	11	No answer	7
total	363	total	363
Characteristics by size and period of existence (age) of the enterprise	Size of surveyed enterprises (number of employees)	Period of existence of the surveyed enterprises	
Mean	342*	18,6 years	
Standard deviation	3999,91	12,6 years	
Median	13	17	
Minimum	5	3	
Maximum	74000	100	

*value overestimated by the number of employees in the largest surveyed company - 74,000.

Source: own elaboration.

The surveyed sample, consisting primarily of small and medium-sized Polish enterprises from diverse sectors, provides a robust empirical basis for analyzing the proposed relationships. This diverse composition ensures that the findings reflect real-world dynamics across various organizational contexts.

3.2. Measures

The questionnaire was composed of five main parts, related to organizational unlearning, organizational creativity, innovations, competitive advantage and environmental dynamism. **Competitive advantage** was measured using the tool proposed by Schilke (2014), consisting of 6 statements assessed on a 7-point Likert scale. Cronbach alpha equaled 0.896, which signifies high internal consistency.

The decision to prioritize competitive advantage over financial metrics is grounded in the acknowledgment that sustainable success in today's business landscape extends beyond mere financial indicators. While financial metrics offer valuable insights into short-term performance, they often fall short in capturing the multifaceted and dynamic nature of competitiveness. Focusing on competitive advantage allows for a more comprehensive evaluation of an organization's capacity to innovate, adapt, and thrive in diverse environments. Unlike financial metrics, which may not fully reflect an organization's innovative prowess or its ability to navigate unforeseen challenges, competitive advantage encompasses a broader spectrum of strategic capabilities (Porter, 1985). This approach aligns with the central theme of the study, which explores the interplay between organizational creativity, innovation, and the achievement of a competitive edge. By prioritizing competitive advantage, the analysis aims to unravel the strategic underpinnings that contribute to sustained organizational success, transcending the confines of traditional financial metrics. Additionally, Anderson and Eshima (2011) identify two additional benefits of using subjective measures of organizational

effectiveness. Firstly, in small and medium-sized enterprises, the perception of success or failure strongly influences staff choices. Secondly, the use of subjective measures facilitates comparisons between businesses operating in different contexts (such as different industries, markets, or economic conditions). Therefore, vital sources of information about a company's effectiveness include comparisons with competitors (Birley and Westhead, 1990).

Organizational unlearning was measured using six-item scale suggested by Lyu, Yang, Zhang, Teo & Guo (2020). Each item was measured on a seven-point Likert scale, and the reliability coefficient for the scale used was 0.845. **Organizational creativity** was measured using a tool developed by Bratnicka-Myśliwiec (2017), with Cronbach's alpha for 12 items assessed on a seven-point Likert scale amounting to 0.893. The measurement of the **environmental dynamism** was carried out using a tool developed by Sutcliffe (1994). Cronbach's alpha for the whole scale equalled 0.653. Finally, the **innovation output** (a mediator in our study) was measured following the Oslo Manual (2018) recommendations (we asked for the number of innovations – new products, services, and organizational solutions).

In our study, two control variables, namely the age and size of the company, were incorporated. These control variables were introduced with the primary aim of mitigating the potential influence of exogenous factors on the results of our conducted tests. Company age was operationalized as the number of years since its establishment. This addition of company age as a control variable is particularly pertinent as it is frequently considered a critical factor in explaining firm performance. Furthermore, the age of a firm may act as a moderating factor in the relationship between innovation capabilities, effectiveness, and entrepreneurial orientation, thereby impacting organizational effectiveness (Runyan, Droge, Swinney, 2008). On the other hand, firm size, measured in terms of the number of full-time equivalent employees, was also included as a control variable. This selection is substantiated by the commonly held perception that firm size plays a crucial role in elucidating a company's operational efficiency (e.g., Covin, Green, Slevin, 2006) and innovative capabilities (e.g., Herrera, Sánchez-González, 2013).

4. Research results

In order to enhance our comprehension of the relationships between the studied constructs, we conducted a correlation analysis (see Table 2).

Table 2.*Descriptives and correlations (n = 363)*

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
(1) Competitive advantage	1						
(2) Organizational unlearning	.306**	1					
(3) Organizational creativity	.434**	.508**	1				
(4) Innovations (log10)	.224**	.196**	.325**	1			
(5) Environmental dynamism	.150**	.102	.325**	.175**	1		
(6) Size (log10)	.289**	.066	.058	.279**	.032	1	
(7) Age (log10)	.085	-.031	-.112*	.055	-.001	.419**	1
Mean	4.365	5.034	4.784	0.725	4.304	1.332	1.167
Std. deviation	0.945	0.946	0.802	0.531	1.054	0.619	0.314

**. Correlation is significant at $p < 0.01$ (two-tailed).*. Correlation is significant at $p < 0.05$ (two-tailed).

Source: own elaboration.

The correlation table underscores significant and moderately strong relationships among the studied constructs. Competitive advantage demonstrates positive associations with various factors: organizational unlearning ($r = 0.306$, $p < 0.01$), organizational creativity ($r = 0.434$, $p < 0.01$), innovations ($r = 0.224$, $p < 0.01$), environmental dynamism ($r = 0.150$, $p < 0.01$), and organization size ($r = 0.289$, $p < 0.01$). The positive correlations imply that higher levels of organizational unlearning, creativity, innovation, environmental dynamism, and larger organizational size contribute to an augmented perceived competitive advantage. Notably, organizational unlearning exhibits significant relationships with organizational creativity ($r = 0.508$, $p < 0.01$) and the number of innovations ($r = 0.196$, $p < 0.01$).

Organizational creativity, in turn, correlates positively with the number of innovations ($r = 0.325$, $p < 0.01$) and environmental dynamism ($r = 0.325$, $p < 0.01$). However, it weakly and negatively correlates with the age of the organization ($r = -0.112$, $p < 0.05$). The number of innovations is positively associated with environmental dynamism ($r = 0.175$, $p < 0.01$) and organizational size ($r = 0.279$, $p < 0.01$). Additionally, age and organizational size exhibit a positive interrelation ($r = 0.419$, $p < 0.01$), indicating that older organizations tend to be larger.

While the correlations are not exceptionally high, a precautionary note is given to assess multicollinearity. To address this concern, we conducted a variance inflation factors analysis in SPSS. Specifically, a simple regression model with competitive advantage as the dependent variable and others as independent variables was executed, and the results are detailed in Table 3.

Table 3.*Collinearity assessment: regression model*

Model summary ^a								
Model summary	R		R-square	Corrected r-squared	Standard error			
1	0.517		0.267	0.255	0.817			
Anova statistics								
Model		Sum of squares		df	Mean square	F	p-value	
1	Regression		86.433	6	14.406	21.601	<.001 ^b	
	Remainder		237.414	356	0.667			
	Total		323.847	362				
Model		Beta Coefficients		Standardized coefficients	t	p-value	Multicollinearity statistics	
		B	Standard error	Beta			Tollerance	VIF
(Constant)		1.154	.358		3.228	.001		
Organizational unlearning		.102	.053	.102	1.920	.056	.735	1.361
Organizational creativity		.428	.068	.363	6.291	<.001	.618	1.617
Innovations (log10)		.025	.089	.014	.281	.779	.820	1.220
Environmental dynamism		.011	.043	.012	.242	.809	.882	1.134
Size (log10)		.376	.080	.246	4.720	<.001	.757	1.321
Age (log10)		.076	.152	.025	.498	.619	.804	1.244

a: DV: competitive advantage.

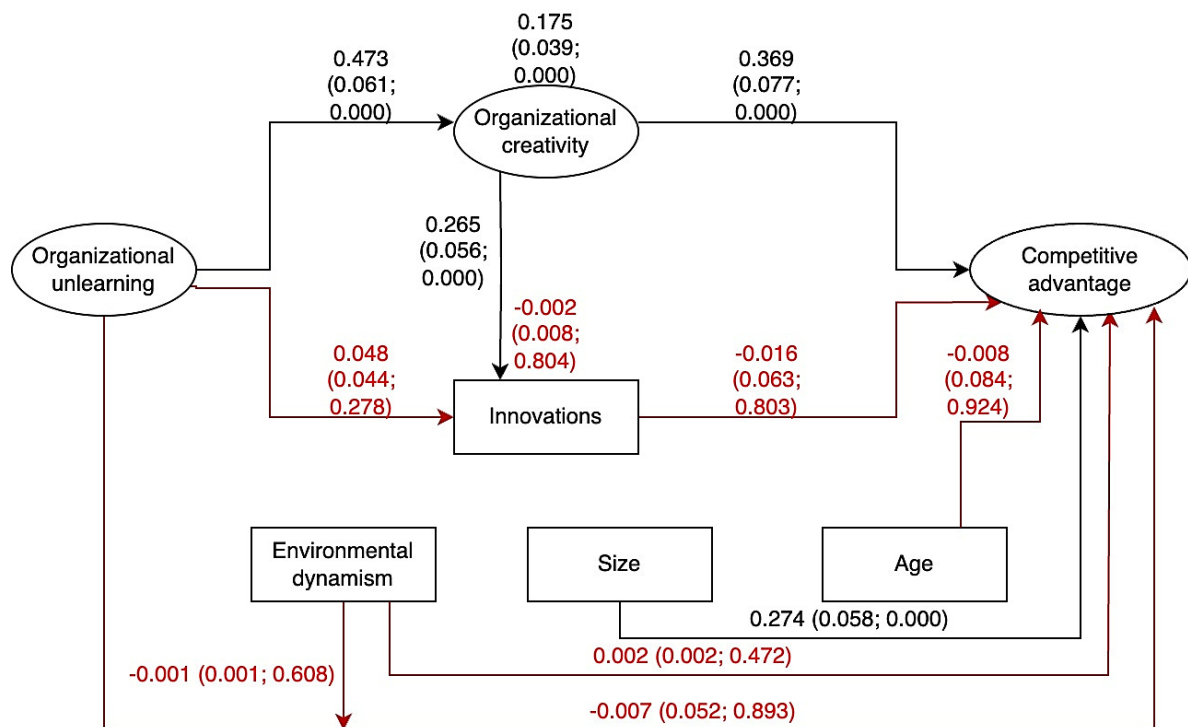
b: IV: organizational unlearning, organizational creativity, innovations (log10), environmental dynamism, size (log10), age (log10).

Source: own elaboration.

As the variance inflation factor (VIF) values remain below 5, a commonly accepted threshold for identifying multicollinearity among independent variables (IVs), we assert that the variables are not strongly correlated (Thompson et al., 2017). This suggests that the robustness and reliability of our analyses remain unaffected, as the correlation strength does not pose a significant risk of multicollinearity-induced distortions.

In the following phase of our study, we delved into the relationships among the variables under investigation through the application of structural equation modeling (SEM). In this analytical framework, we conceptualized competitive advantage, organizational unlearning, and organizational creativity as latent variables, allowing us to capture the underlying constructs that contribute to these phenomena. To operationalize our measures, we employed logarithms for the number of innovations, organizational size, and age. This logarithmic transformation enhances the interpretability and statistical properties of these variables. Additionally, to account for moderating effects, we introduced a metavariate for environmental dynamism. This decision was made to navigate the inherent complexities associated with modeling moderation using latent variables, a task that can pose substantial analytical challenges.

The SEM analysis was performed using the Mplus statistical software. Given the nuanced nature of our research model, incorporating latent variables and a moderated-mediation framework, we opted for a random type of analysis with an integration algorithm. The estimator was set as maximum likelihood, and we conducted 10,000 iterations with a convergence criterion set at 0.00005 to ensure robust results. To fortify the reliability of our findings and mitigate the impact of sample size on statistical outcomes, we employed bootstrapping during the analysis (5000 draws). This resampling technique aids in generating a distribution of estimates, offering a more stable understanding of the relationships within our model. Furthermore, our mediation analysis was facilitated through the 'model constraint' option, allowing us to assess and quantify the indirect effects within our specified model. This approach adds depth to our exploration of the interplay between variables, providing a more comprehensive understanding of the mechanisms at play in our research framework. Figure 2 portrays, in simplified form, relationships between variables, and detailed information is enclosed in table 4.



Legend: over lines model estimates are provided, with se and p-values in brackets.
Black lines: statistically significant relationships; red lines: insignificant relationships.

Figure 2. Graphical representation of relationships between studied variables

Source: own elaboration using drawio.net free online drawing tool.

Table 4.*Model estimation results*

Model fit information				
Number of free parameters		95		
Information criteria	Akaike (AIC)	24084.91		
	Bayesian (BIC)	24453.03		
	Sample-size adjusted BIC (n*=(n+2)/24)	24151.65		
Regression coefficients				
		Estimate	Standard error	Two-tailed p-value
DV: Competitive advantage				
Organizational Unlearning → Competitive advantage (H1)		-0.007	0.092	0.939
Organizational Creativity → Competitive advantage (H2)		0.369	0.102	0.000
Innovation → Competitive advantage (H5)		-0.016	0.070	0.821
Environmental dynamism → Competitive advantage (H10)		0.002	0.013	0.904
Size → Competitive advantage		0.274	0.064	0.000
Age → Competitive advantage		-0.008	0.094	0.932
Organizational Unlearning → Organizational Creativity → Competitive advantage (mediation) (H4)		0.175	0.051	0.001
Organizational Unlearning → Innovation → Competitive advantage (mediation) (H8)		-0.001	0.004	0.867
Organizational Unlearning → Organizational Creativity → Innovation → Competitive advantage (mediation) (H9)		-0.002	0.009	0.829
Total effect (direct and indirect) of organizational unlearning, organizational creativity, and innovation on competitive advantage		0.165	0.087	0.057*
Organizational Unlearning*Environmental Dynamism → Competitive advantage (moderation) (H11)		-0.001	0.013	0.957
DV: Organizational creativity				
Organizational Unlearning → Organizational Creativity (H3)		0.473	0.057	0.000
Size → Organizational Creativity		0.043	0.075	0.271
Age → Organizational Creativity		-0.078	0.138	0.575
DV: Innovation				
Organizational Creativity → Innovation (H7)		0.265	0.070	0.000
Organizational Unlearning → Innovation (H6)		0.048	0.048	0.323
Size → Innovation		0.082	0.075	0.271
Age → Innovation		0.591	0.186	0.001

Significant parameters are highlighted.

*the effect is significant at $p < 0.1$.

Source: own elaboration.

Our analysis yielded findings regarding the relationships between the studied variables. Contrary to our initial hypothesis (H1), we did not observe a direct association between organizational unlearning and competitive advantage. However, our second hypothesis (H2), suggesting a positive influence of organizational creativity on competitive advantage, found substantial support in the data.

Additionally, organizational unlearning emerged as an important determinant of organizational creativity, aligning with our third hypothesis (H3). The mediation analysis further unveiled a significant indirect effect, indicating that the influence of organizational unlearning on competitive advantage operates through the pathway of organizational creativity, providing robust support for our fourth hypothesis (H4).

Turning to innovations, our findings affirm the importance of organizational creativity (H7), as it significantly contributes to the generation of new organizational solutions. However, contrary to our expectations, organizational unlearning did not exhibit a direct influence on the number of innovations, leading to the rejection of H6. Interestingly, the anticipated impact of innovations on competitive advantage (H5) did not materialize in our results, suggesting a non-significant relationship. Exploring further, the indirect effects from organizational unlearning to competitive advantage, mediated through both innovation and organizational creativity, were found to be insignificant. Consequently, hypotheses H8 and H9 were not supported, challenging the notion of an indirect influence.

Turning to the relationships involving environmental dynamism, neither the direct effect (H10) nor the interaction with organizational unlearning (H11) yielded significance. Both hypotheses were therefore rejected, indicating that these factors do not play a substantial role in predicting competitive advantage in our model.

In an interesting twist, beyond our hypothesized relationships, organizational size emerged as a significant predictor of competitive advantage. Additionally, organizational age exhibited a positive impact on the number of innovations, shedding light on unforeseen but valuable associations within our study context. These findings contribute to a more comprehensive understanding of the dynamics at play in the examined organizational settings.

5. Discussion

The paper focuses on investigating relationships between organizational unlearning, organizational creativity, innovation, competitive advantage, and environmental dynamism. Our study does not confirm the direct influence of organizational unlearning on competitive advantage (H1), contrary to other research results (Leal-Rodriguez et al., 2014; Wang, Qi, Zhao, 2019). This is partially explained considering the mediating effect organizational creativity plays in this relationship (H4). Thus, organizational ability to create new and valuable ideas help serve as a mechanism unveiling the otherwise unobservable relationship between organizational unlearning and competitive advantage. Both, relationships between organizational unlearning and organizational creativity (H3) and organizational creativity and competitive advantage (H2) are significant, which reaffirms previous results, as suggested by Klammer and Gueldenberg (2020), and Zameer, Wang and Yasmeen (2020).

Surprisingly, innovation output, perceived as the number of new organizational solutions, products and processes does not play a significant role in our model. Neither the relationships between organizational unlearning and innovation (H6), nor the relationship between innovation and competitive advantage (H5) are significant, which further contributes to our knowledge on the role of innovation in organizational processes, countering research results of

Leal-Rodriguez et al. (2014) and shedding a different light on the results of Polater (2023). Consequently, also mediation effects of innovation are insignificant (H8 & H9). Our study results imply that competitive advantage and innovation may be perceived as distant phenomena. One plausible explanation for this observed phenomenon could be rooted in the complexity of organizational dynamics. It is conceivable that decision-makers, when prioritizing strategies for achieving competitive advantage, may place emphasis on existing strengths, operational efficiencies, or market positioning, while innovation, often characterized by risk and uncertainty, may be viewed as a separate and independent pursuit (Ireland, Hitt, 2005). Another consideration is that the time horizon for perceiving the outcomes of competitive advantage and innovation could differ. Achieving a competitive advantage may yield more immediate and tangible results, while the full impact of innovation may require a longer gestation period (Hana, 2013). Further research and exploration into the underlying perceptions and decision-making criteria of organizational leaders could shed additional light on this intriguing dynamic.

Innovations and competitive advantage may be also perceived as distinct paths to success. This implies that organizations can achieve success through different mechanisms, and at the same time, the lack of a significant correlation between innovations and competitive advantage suggests that one does not necessarily lead to the other.

As McGrath, Tsai, Venkataraman, and MacMillan (1996) point out, a company should first establish a clear competitive advantage before expecting benefits from innovation. Competitive advantage can thus serve as a foundational element, enabling the company to compete effectively in the market, and innovations can then be utilized as a means to strengthen this position and achieve long-term success.

On the other hand, our study supports the notion of organizational creativity for boosting innovations in organization (H7), which confirms previous studies' results (Acar, Tarakci, Van Knippenberg, 2019). Organizational creativity, as evidenced by the ability to think beyond conventional boundaries, encourages a culture of exploration, experimentation, and idea generation within the organizational framework. This creative ethos, when nurtured and embedded within the organizational culture, stimulates the development of novel solutions, products, and processes (De Vasconcellos, Garrido, Parente, 2019).

Environmental dynamism does not appear to alter the main relationship between organizational unlearning and competitive advantage (H11), indicating that unlearning remains unrelated to competitive advantage regardless of the perceived level of environmental dynamism. This finding contradicts the research results of Wang et al. (2022). In summary, organizational unlearning assists organizations in challenging their previous assumptions and past practices, which may have been hindering their progress. This ability could be facilitated by mediating mechanisms that allow organizations to generate new ideas and solutions to complex problems, introduce innovative strategies, and adopt approaches that enable them to

develop and survive even in challenging market conditions. The key role in this process is played by organizational creativity.

The research results achieved have significant implications for managerial practice. When suggesting directions to management to enhance their competitive advantage, it is possible to emphasize the promotion of managerial activities aimed at fostering an organizational culture conducive to rejecting inadequate practices, eliminating obsolete knowledge, and creating conditions that support the process of discarding undesirable patterns of behavior or habits within the organization. In line with Ruíz, Gutiérrez, Martínez-Caro, and Cegarra-Navarro (2017), we propose that, in facilitating unlearning processes, management should prioritize activities involving the entire organizational workforce and foster effective communication and idea exchange.

Furthermore, it is beneficial for organizational decision-makers to facilitate organizational creativity, as it enables the ability to unlearn ineffective processes and practices, influencing competitive advantage (Martins, Martins, Pereira, 2017). To elaborate, this could involve promoting active participation in meetings, facilitating collaborative teamwork, and encouraging involvement in projects characterized by diverse tasks and a varied composition of participating employees.

The implications of our study suggest that organizations seeking to enhance their innovative capabilities should prioritize fostering a culture that nurtures and encourages creativity. This may involve incentivizing creative thinking, providing platforms for idea exchange, and creating an environment that values and supports experimentation (Lasrado, 2019). Also, the role of unlearning remains unaltered no matter the dynamism of the environment. It may signify that unlearning is not just a response to external changes, but a proactive and continuous process embedded in the organizational culture, ensuring long-term competitiveness and success (Sinkula, 2002).

Our study also indicates that the impact of introducing new products, services, and management methods does not always immediately secure a competitive advantage. This phenomenon may be attributed to a time lag, where the effects of newly implemented organizational solutions might require some time to manifest and influence the firm's competitive advantage (Warner, Wäger, 2019). This temporal gap underscores the dynamic nature of organizational adaptation, suggesting that the full realization of benefits from innovations may unfold gradually over time rather than yielding immediate results. The delay in observing enhanced competitive advantage emphasizes the importance of considering a more longitudinal perspective when assessing the true impact of organizational innovations on a firm's overall competitiveness.

Organizational unlearning is a concept that inherently embodies intricate and multidimensional facets. It encompasses not only the shedding of outdated knowledge and routines but also the reconfiguration of mental models that guide an organization's actions and decisions (Fiol, O'Connor, 2017; Klammer, Gueldenberg, 2019). Such complexity can pose

a significant challenge when attempting to comprehensively capture it through quantitative means alone. In a quantitative study, researchers often rely on simplifying the multifaceted nature of organizational unlearning by operationalizing it into measurable variables. While this approach offers statistical rigor, it may inadvertently overlook the nuanced and context-specific aspects that define the process of unlearning within a particular organization. Quantitative analyses can provide valuable insights into overarching trends and associations, but they might miss the richness of individual experiences, the unique barriers to unlearning, and the subtle shifts in organizational culture. To address these inherent limitations, researchers should consider a mixed-methods approach that combines quantitative data with qualitative insights (Kluge et al., 2019).

Qualitative methods, such as in-depth interviews, focus groups, or case studies, offer a valuable avenue for delving deeper into the complexities of organizational unlearning as well (Matsuo, 2019). These methods allow researchers to explore the 'how' and 'why' questions, providing a more comprehensive understanding of the phenomena that quantitative measures alone cannot fully capture. Through interviews, researchers can gain access to the narratives and personal experiences of individuals involved in the unlearning process. These narratives often reveal the challenges, cognitive shifts, and contextual factors that influence unlearning in an organization (Sharma, Lenka, 2022).

Case studies, on the other hand, enable a detailed exploration of specific instances of unlearning, offering a context-rich perspective on the interplay between organizational culture, leadership, and the unlearning journey (Snihur, 2018). By integrating qualitative methods into their research, scholars can navigate the intricacies of organizational unlearning with greater sensitivity. This approach not only enriches the depth of understanding but also helps in contextualizing quantitative findings. It is, therefore, a well-rounded strategy to ensure that the multifaceted nature of organizational unlearning is adequately explored, preserving the richness and nuances of this vital organizational process.

Investigating how organizational unlearning develops over time is crucial. Longitudinal studies could offer a powerful lens through which to examine the dynamic nature of unlearning processes within organizations. Such studies may be helpful in providing a comprehensive understanding of how unlearning unfolds, evolves, and influences organizational development over time (Kluge, 2023). Exploring the antecedents and triggers that prompt organizations to initiate unlearning processes also seems to be a fruitful path for future research. Investigating the role of external shocks, such as technological disruptions and economic crises, along with internal factors like leadership changes and strategic shifts, can provide a comprehensive view of what drives unlearning efforts (Lyu et al., 2020). Additionally, the examination of the influence of organizational context on unlearning can be an interesting area of study. Different industries, organizational sizes, and cultures may impact how unlearning is received and enacted (Becker, 2010). Comparative studies across various contexts can yield valuable insights into the contextual variations of unlearning.

Analyzing leadership behaviors, styles, and strategies that facilitate effective unlearning can provide practical insights into how leaders can navigate and encourage a culture of adaptability within their organizations. These insights may include understanding the role of leadership in fostering a climate that values continuous unlearning, recognizing the importance of open communication, and identifying specific leadership practices that contribute to successful organizational unlearning initiatives. By delving into these aspects, organizations can gain actionable knowledge on how to cultivate an environment that embraces change and innovation, ultimately contributing to their long-term success and competitiveness in a rapidly evolving business landscape (Kim, Park, 2022).

Conducting cross-cultural studies to understand and explore how unlearning is comprehended and implemented in various cultural contexts is valuable (Adler, Aycan, 2018). Such research can offer valuable insights into the diverse ways cultural factors influence the dynamics of unlearning processes. This, in turn, enriches our understanding of cross-cultural management, facilitating the development of more effective strategies and approaches in diverse organizational settings.

One limitation of our study is the potential for single source bias, wherein reliance on a singular information channel may introduce a skewed perspective. This limitation could restrict the comprehensiveness of our findings as different sources might present varying viewpoints or interpretations (Garger, 2008). To address this, future research endeavors should prioritize diversifying information sources, consulting multiple reputable outlets, and critically evaluating data. This approach aims to mitigate the risk of bias and ensures a more balanced and nuanced understanding of the relationships explored.

In exploring the dynamics of organizational success, our study deliberately centers on competitive advantage, recognizing its significance beyond conventional financial metrics. While the choice aligns with the recognition that sustainable success transcends mere financial indicators, it introduces a potential bias toward a qualitative perspective. The reliance on subjective measures, as indicated by Anderson and Eshima (2011), may lead to a limited understanding of organizational effectiveness, particularly in terms of quantifiable outcomes. This limitation might hinder a more nuanced assessment of short-term financial performance, potentially overlooking crucial insights offered by traditional financial metrics. Additionally, the complexity of competitive advantage as a focal point may introduce challenges in its operationalization, potentially impacting the precision of measurement. Future research endeavors should consider addressing this limitation by exploring a balanced approach that integrates both qualitative and quantitative perspectives, ensuring a more comprehensive evaluation of organizational effectiveness.

6. Summary

The dynamic relationship between organizational creativity and innovation emerges as a vital catalyst for fostering a competitive advantage in the contemporary business landscape. The paper underscores the significance of embracing novel ideas while actively shedding outdated concepts, routines, and methodologies through the process of organizational unlearning. Organizational creativity, characterized by the generation of new and valuable ideas, not only enhances innovation but also serves as a driving force for adapting, competing, and achieving long-term development. The synergy of innovation, flexibility, and strategic acumen equips organizations with a potent mechanism for thriving amidst the complexities and uncertainties of the modern business environment.

Moreover, the paper explores the mediating role of organizational creativity in the nexus between organizational unlearning and competitive advantage. It argues that organizational creativity serves as a crucial mediator, facilitating the translation of unlearned insights into innovative solutions. Supported by relevant literature, the study proposes hypotheses that highlight the interplay between organizational creativity, unlearning, and competitive advantage. By establishing these connections, the paper provides insights for organizations seeking to enhance their adaptability, resilience, and competitive positioning in the face of evolving business environments.

The role of innovation in shaping organizational competitive advantage is a multifaceted and strategic imperative. The paper posits that innovation, particularly in the form of new and valuable solutions, products, and processes, serves as a potent catalyst for creating sustainable competitive advantage. Highly innovative organizations demonstrate increased structural flexibility, enabling them to navigate and thrive in dynamic market conditions. The interplay between innovation, flexibility, and strategic acumen positions these firms to effectively exploit opportunities, outperform competitors, and flourish amidst business complexities.

The study delves into the relationships between organizational unlearning, creativity, and innovation. Scholars argue that organizational unlearning acts as a prerequisite for nurturing creativity, further contributing to the conceptualization and implementation of innovations. By shedding light on these relationships, the paper emphasizes the proactive role of unlearning in fostering innovation and, subsequently, competitive advantage. The proposed hypotheses provide a theoretical framework for understanding how organizational creativity and innovation mediate the link between unlearning and competitive advantage. Contrary to some existing research, the findings suggest that the role of organizational unlearning remains unaltered regardless of the perceived level of environmental dynamism. This implies that unlearning is not merely a reactive response to external changes, but a proactive and continuous process ingrained in organizational culture, contributing to long-term competitiveness and success, what is a valuable insight for organizations seeking to thrive in uncertain and turbulent business environments.

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RISKS ASSOCIATED WITH THE SELECTION OF A DESIGNER IN A TENDER PROCESS

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Purpose: The main objective of this article is an attempt to define the risk factors associated with the selection of a designer in a tender procedure on the example of a biogas plant in Olsztyn. The study aims to understand what risks may arise in the process of selecting a designer and what actions can be taken to minimize them. The results are expected to provide practical guidance for decision-makers and tender participants to increase the efficiency and safety of the entire process.

Design/methodology/approach: The theoretical part of the study is based on a review of the literature and familiarization with the tender procedure of the discussed investment. The empirical part, on the other hand, consists of a seminar and a survey. In order to analyse the results obtained, risk assessments were carried out according to the classical approach as a product of the probability of their occurrence and the effects to which they may lead.

Findings: Choosing the right designer is crucial for the success of the entire investment. The decision made is not always optimal, despite the use of different selection methods, also taking into account computer tools supporting this process.

Research limitations/implications: The limitations of the research are related to conducting the analysis among a selected, small group of designers. Future studies should be extended to include a larger group of experts and for another biogas plant investment in order to compare the results. Also, the interpretation of expert data could have been carried out in many different ways.

Practical implications: So far, no similar survey has been carried out, which may be helpful for further tender procedures of this type to raise the investor's awareness when making decisions.

Originality/value: The article attempts to identify risk factors, thus showing how complex and ambiguous the decision-making process is, especially in tender proceedings, where many criteria are evaluated, and the choice made is not always optimal. Particular attention should be paid to the important aspects of risk in order to reduce them in the future. The article is mainly addressed to decision-makers of tender processes, but it is also universal in nature, because risk and decision-making accompany people at every step.

Keywords: risk management, tender procedure, biogas plant, multi-criteria decision making, risk factors.

Category of the paper: research paper, case study.

1. Introduction

1.1. Biogas plant investment

In construction activities, in the case of large investments financed from public funds, and also included in the group of those that may affect the environment, it is necessary to develop several variants and then choose the solution that meets the previously specified requirements to the highest extent (Szafranko, Jurczak, 2023). In the first step, the investor defines the goals of the project, specifies requirements such as efficiency, price, implementation time, compliance with regulations, adaptation of the project to local conditions, available raw materials. Then he sets the evaluation criteria, such as the designer's experience, references, innovation of activities. When the offers are received on the predetermined date, the selection is made. Due to the complexity of the process, this is not a clear and obvious topic. The selection is related to the bidder's analysis, taking into account the set criteria, so it is a multi-criteria problem (Leśniak, 2021; Leśniak, Radziejowska, 2017). The decision made is not always optimal, despite the use of different selection methods, also taking into account computer tools supporting this process. It often turns out that existing methods produce different results, so which one is the best? Does it exist or is it possible for it to be created?

A sustainable future is now becoming the watchword in many industries, including the construction sector. High exhaust emissions and environmental pollution are considered to be one of the main causes of climate change. In order to prevent these adverse phenomena, a policy focused on the use of renewable energy sources (RES) and the reuse of raw materials is being introduced. One such production plant that processes organic waste is a biogas plant. The product obtained in it is used as a renewable energy source, helps to reduce greenhouse gas emissions, thus creating a closed loop of raw materials (Chludziński, Duda, 2024).

The construction of a biogas plant is a complex undertaking that requires careful preparation, planning and implementation. In the first stage, which is crucial for further processes, a tender is announced to select the entity responsible for the implementation of the investment. The tender procedure is a process in which the contracting authority selects a contractor to perform a specific task, delivery or service. The main steps of this process are presented in Figure 1.

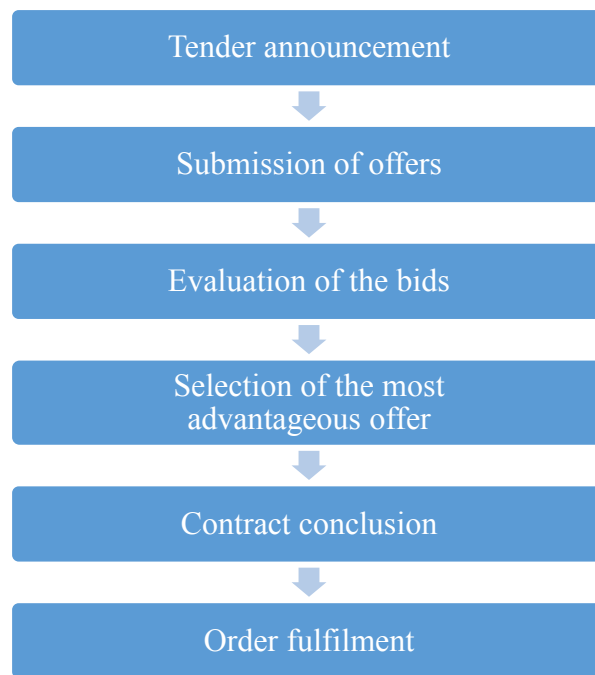


Figure 1. The main stages of the tender procedure.

Source: own study based on (USTAWA: Prawo Zamówień Publicznych, 2019).

One of the people involved in the implementation of the biogas plant investment is the designer. Choosing a project team is critical to your investment and its long-term success. The designer is responsible for preparing technical documentation, which is the foundation of the entire project. It is important that the investor can establish an effective relationship with him. In the tender procedure, the selection should be made on the basis of an objective assessment, guided by pre-established criteria, which should focus on design skills and experience.

1.2. Decision-making risks

Risk is an unavoidable element accompanying decision-making. At the time of making a choice, one does not have full information about potential external or internal factors, i.e. there is uncertainty in the decision and with it comes risk (Project Management Institute, 2003; Ward, Chapman, 2003). In order to minimize the probability of risk for a given investment, it is worth looking at it in the long term and referring it to similar projects that have already been completed. Hence, it is necessary to forecast the future effects of current decisions, identify possible threats and take preventive actions, which is the subject of many studies. There are many approaches to risk management in different areas of life. In Poland, the ISO 31000 standard, created in 2009 by the International Organization for Standardization (ISO), is often used (International Organization for Standardization). Its Polish equivalent is the PN-ISO 31000:2018 standard (PN-ISO 31000:2018 Zarządzanie Ryzykiem – Zasady i Wytyczne, 2018). According to it, risk management can be divided into stages, presented in Figure 2.

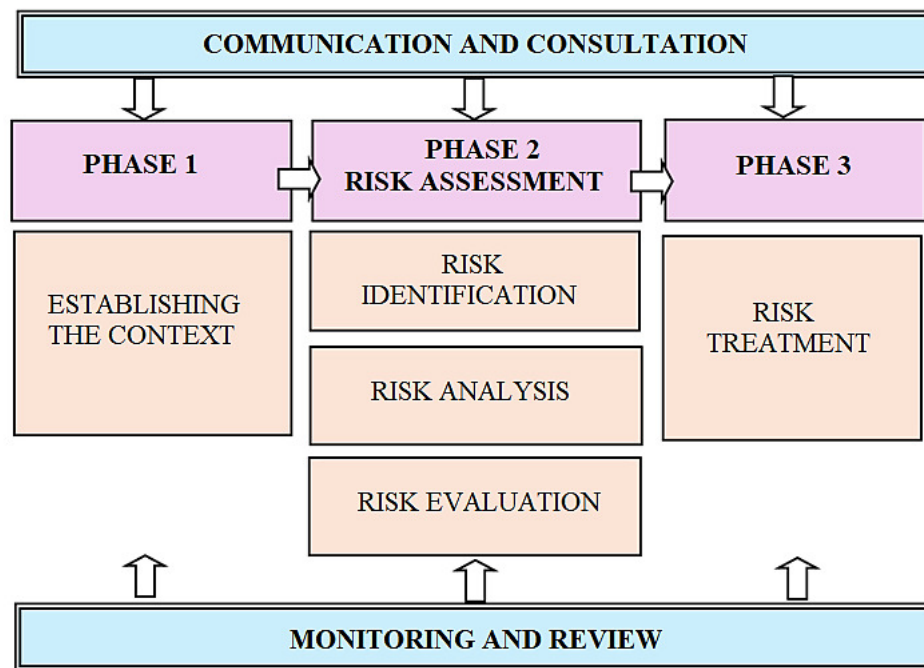


Figure 2. Stages of risk management according to ISO 31000.

Source: own study based on (PN-ISO 31000:2018 Zarządzanie Ryzykiem – Zasady i Wytyczne, 2018).

The essence of the first phase is to define the objectives, scope, investment features and general assumptions. The next phase moves on to the risk assessment stage, which is first to identify the risks, i.e. to identify the factors that may affect the implementation of the project. In this case, it is a good idea to classify them according to accepted principles. Risks are then measured, by determining the probability of their occurrence and the severity of their consequences. For this purpose, qualitative methods are used – descriptive and quantitative, making a hierarchy. The second one is based on mathematical and statistical methods, which makes it more complicated and requires appropriate data. Most often, risk is described as the quotient of the probability of its occurrence and impact on the success of the project (Project Management Institute, 2003) (Formula 1):

$$R = f(P, C) \quad (1)$$

where:

R – risk,

P – the probability of a certain risk occurring,

C – the consequences of the event on the final effect of the project being implemented.

After such an assessment, it can be determined to what extent a given risk is material, whether it can be accepted, and what should be done about it. All this leads to the final phase, i.e. dealing with risk. In the simplest terms, two levels of risk management can be distinguished: the first is associated with the acceptance of risk in which no specific actions are required, and the second – immediate actions are necessary to reduce risks that exceed the tolerance

threshold. Pritchard provided the following categories of risk response methods (Pritchard, 2002):

- risk avoidance,
- risk transfer,
- risk mitigation,
- risk acceptance.

1.3. Risk analysis in biogas plant investment – literature review

The authors of various publications have already undertaken an analysis of the risks to the overall success of a biogas plant project. In Kwestarz (2021), the main factors influencing the implementation of an agricultural biogas plant at the planning and preparation stage of the investment process are identified and presented. The results of an economic analysis over a 15-year operating horizon for investments with two levels of electrical power are included: 0.5 MW and 1 MW. After conducting detailed analyses, it was concluded that the construction of a biogas plant is profitable, estimating a simple payback time of 2-4 years. Other authors have presented a case study of risk analysis in the context of qualitative research based on literature review and surveys (Ligus, Słoński, 2018). The result of the analyses was the conclusion that biogas plants are associated with high risk and require professional management and control throughout the life cycle of the investment. Also the aspects of the operational risk of biogas plants have been discussed in the literature. In (Szymańska, Wieteska, 2017), the operation of biogas plants was assessed for the purpose of covering them with insurance coverage. Attempts have been made to estimate the sum insured, as well as the types and frequency of damage that may occur during the use of this type of facilities.

After reviewing the literature, it was noted that so far the topic of the risk associated with the selection of the biogas plant designer has not been discussed by scientists. Most of the articles focus on general aspects of investment, regulatory and technical risks that may affect the implementation of a biogas plant project. Therefore, it was decided to deepen this topic.

2. Methods

The main objective of this article is an attempt to define the risk factors related to the selection of a designer in a tender procedure on an example. A biogas plant up to 1MW in Olsztyn was selected for evaluation. The author, as a co-designer of the construction documentation for the biogas plant in question and on the basis of his own experience in designing the structure of buildings, identified possible risk factors when selecting the design team. The study aims to understand what risks may arise in the process of selecting a designer and what actions can be taken to minimize them. The results are expected to provide practical

guidance for decision-makers and tender participants to increase the efficiency and safety of the tendering process.

The assumed goals were achieved through a literature review related to the topic and familiarization with the tender procedure of this investment. Then a seminar was organized, to which 14 designers with experience in tenders were invited. Of these, 2 designers participated in the creation of documentation for another biogas plant in previous years and 4 involved in the current project. A discussion was held on the possible risks associated with the selection of a designer for this particular biogas plant project in Olsztyn. First, forms were distributed, on which everyone had the opportunity to give their own objective answer, without consulting a group of experts, to the general issue: "Identify possible risk factors related to the selection of a biogas plant designer in Olsztyn". The responses received were summarized and each of them was publicly discussed, specifying their consequences and proposing remedies to avoid their occurrence. In the next stage, a survey was conducted among the same subjects, in which each identified risk had to be assessed in terms of two parameters: the probability of its occurrence and the effect it may have.

3. Research results

The biogas plant will process organic waste from separate collection and produce biogas and use it in the process of producing renewable electricity and heat. The area of the investment in question is undeveloped areas. The project involves the construction of a complex of buildings for technological purposes of a biogas plant with a capacity of up to 1 MW, together with technical infrastructure and communication in the form of a road and squares. The construction of the following facilities and equipment is planned: a reception hall with a social building, a storage building, cogeneration units, a building for cooling biogas, a mixing tank, an acidification tank, fermentation tanks of the first and second stage, end tanks, pumping station buildings, an underground fire-fighting water tank, an underground rainwater tank, an underground tank for technological wastewater, a drive-on scale, a biogas desulphurization station, an emergency flare, a biofilter.

During the seminar, 14 designers individually identified potential risk factors that may arise when selecting a designer in the tender process for the design of a biogas plant in Olsztyn. The results of such an analysis are presented in Table 1.

In the next stage, the above-mentioned risks were analysed. A survey was carried out in which a group of 14 designers of building structures from the Warmian-Masurian Voivodeship was asked to assess each risk in terms of two parameters: probability of occurrence of the event (P), severity of effects (S). The scores were made on a scale of 1 to 10, with 1 being low probability and little noticeable effect, and 10 being correspondingly high levels of each

factor. On this basis, risk in the classical approach was calculated as a product of probability and consequences. The results are presented in Table 2.

Table 1.

Identified risk factors related to the selection of a designer in the tender procedure for the construction of a biogas plant in Olsztyn

Risk No.	Risk factor	Possible consequences	Countermeasures
1	Insufficient experience in designing biogas plants	- errors in design, underestimation of costs, time, improper selection of technology; - due to insufficient experience, it will take a lot of time to search for solutions, learn the designer, which can lead to significant delays	Specification in the tender requirements of the required experience of the designer in similar investments (e.g. required completion of this type of investment within the last 5 years)
2	Incorrect assessment of legal requirements and regulations – biogas plants require environmental decisions, obtaining various permits (e.g. for waste management, sewage disposal), opinions (sanitary and epidemiological station, fire brigade)	- failure to obtain the required decision, agreement, which in the long run delays the work and may even lead to its complete suspension; - insufficient knowledge of the time needed to settle the case – illogical schedule of work on obtaining legal documents – delays, and therefore also financial losses; - improper handling of an official matter may result in the imposition of penalties	Choosing a designer who has experience in this type of investment, as well as knows local legal regulations and procedures related to environmental and energy issues
3	Incorrect selection of technologies and engineering solutions	- the possibility of a failure and, in a worse situation, a construction disaster; - insufficient capacity of biogas plants; - suboptimal use of resources, e.g. raw materials for biogas production, energy	Selection of a designer with experience in the selection of biogas technologies, consultations with industry experts
4	Untimely completion of the project	- delays in the schedule – this may affect the delay in the start of construction of the biogas plant, lead to additional costs, penalties	Selection of a designer with experience, a detailed ("good") implementation plan, with a stable financial situation
5	Lack of contacts, cooperation with appropriate contractors and industry specialists	- the designer may encounter problems related to the implementation, e.g. it is difficult for him to find co-workers – industry specialists, specialist construction teams, it is more difficult to obtain information about technical and material solutions	At the tender stage, checking whether the designer cooperates with contractors and whether he has positive references from previous partners
6	Failure to adapt the design to local conditions - the designer may not take into account local conditions such as land, climatic conditions, availability of raw materials, local standards and regulations	- failure to adapt the biogas plant to the actual needs	Selection of a designer who will conduct a detailed analysis of local conditions, such as geotechnical and hydrogeological surveys, and will also take into account the specificity of Olsztyn in the project

Cont. table 1.

7	Communication and coordination problems – insufficient communication between the designer, investor, contractors and other stakeholders	- it can lead to delays, errors, misunderstandings, difficulties in the implementation of the project	Selecting a designer who has experience in managing large projects, has the appropriate competences in coordination and communication with all parties to the project
8	Language barriers may arise when designers from different countries collaborate	- disruptions in the implementation of the project, unnecessary conflicts, lack of support in the implementation of tasks	Selection of a designer with experience in cooperation with a foreign partner, fluent in English
9	Disruptions in data exchange between designers – lack of hardware compatibility with the necessary software or lack of ability to use technological solutions	- designers work with outdated files; - the need to make constant adjustments due to a lack of coordination	Selecting a designer who has experience in managing large projects, has the appropriate competences in coordination and communication with all parties to the project
10	Failure to take into account social and local aspects, failure to take into account the possible impact of the future investment on the environment	- social protests, delays in obtaining permits, arrangements, decisions	Consultation with the local community and authorities before the start of project work, taking into account the aspects discussed and ongoing contacts
11	Risk of miscalculations, e.g. biogas plant efficiency	- suboptimal biogas and energy production, affecting the profitability of the project	Checking the designer's skills in the field of accurate energy calculations, optimization of biogas production technology – checking the designer's experience
12	The lack of a financial reserve by the designer may lead to staff shortages	- budget overrun – related to market conditions, such as salary increases for specific positions (the designer hires a team, and such an increase in costs may lead to a situation where he will not be able to hire enough employees or with appropriate competences)	Choosing a designer who has experience managing large projects
13	The designer will not know the new technologies used to build a biogas plant (a biogas plant is associated with a large technological diversity and the need to use current solutions)	- designing technology that will not be optimal or will not meet the expectations; - if the designer wants to use new technologies, he will first have to familiarize himself with them, which causes delays	Selection of a designer who has experience in similar investments, who is up to date with new technologies used in the construction of biogas plants, who has partners in the technology industry – design assistance
14	Low returns on investment when the designer does not optimize materials, cross-sections, processes, and technologies	- lower profits from biogas production for the investor	Choosing a designer who has experience in similar investments, who knows and uses modern technologies

Source: own research.

Table 2.*Results of the assessment of identified risks – classic risk approach*

Risk No.	Probability P (1-10)	Effects S (1-10)	P·S
1	4	10	40
2	6	7	42
3	7	8	56
4	8	8	64
5	7	5	35
6	4	8	32
7	6	6	36
8	6	8	48
9	5	6	30
10	6	8	48
11	3	10	30
12	2	7	14
13	5	7	35
14	3	9	27

Source: own research.

4. Discussions

The conducted analyses allowed to determine the risk associated with the selection of the designer of the biogas plant in Olsztyn. High P·S values indicate a high level of risk. In the case of the product $P \cdot S$, the maximum value that could be reached was 100. For this analysis, based on the results presented in Table 2, the following classification was established:

- $P \cdot S \geq 50$ – very high risk – immediate corrective action should be taken,
- $30 \leq P \cdot S < 50$ – high risk – corrective action should be taken, but it may not be necessary to apply them,
- $P \cdot S < 30$ – acceptable risk – corrective action can be taken, but the risk does not have a key impact.

According to the above classification, the risks are grouped in Table 3 and ranked from most significant to least for better clarity.

This summary shows that the highest risk in the discussed example is the untimely completion of the project (4) and the improper selection of technologies and engineering solutions (3). Equally high risk was identified for factors resulting from language barriers (8) and social aspects (10), and interestingly, they were assessed in exactly the same way. It is worth noting that in the case of insufficient experience in designing biogas plants (1) and with the risk of incorrect calculations (11), the effects were assessed as 10, i.e. the most severe, so it is important that such situations do not occur, because they can bring significant losses. Such an analysis of individual risks allows you to focus more on them, think about how you can prevent them or how to prepare for their possible occurrence.

Table 3.*Summary of identified risks by product value $P \cdot S$*

Risk No.	Probability P (1-10)	Effects S (1-10)	P·S
4	8	8	64
3	7	8	56
8	6	8	48
10	6	8	48
2	6	7	42
1	4	10	40
7	6	6	36
5	7	5	35
13	5	7	35
6	4	8	32
9	5	6	30
11	3	10	30
14	3	9	27
12	2	7	14

Source: own research.

In the available literature, no direct publications focusing exclusively on the bidding risks associated with the selection of a biogas plant designer were found. However, identified factors such as insufficient experience of the designer, underestimation of investment costs or non-compliance of the design documentation with local regulations have been included in Kwestarz (2021). According to the U.S. Environmental Protection Agency (U.S. Environmental Protection Agency, 2020), an effective selection of a designer should take into account not only the criterion of price, but precisely the experience in similar projects, the ability to manage risks or knowledge of legislation.

5. Conclusions

The conducted research allowed to identify risk factors related to the selection of a designer in the tender procedure for the construction of a biogas plant in Olsztyn. So far, no similar study has been carried out, which may be helpful for further tender procedures of this type. Particular attention should be paid to the important aspects of risk in order to reduce them in the future. During the tender process, it is crucial to conduct a detailed analysis of the designer's financial capacity. Improper assessment can lead to liquidity problems, which can result in delays or non-completion of the project. The designer must have appropriate qualifications and experience in the implementation of similar projects. Lack of appropriate competence can lead to design errors that can affect the quality and safety of implementation. Also, improper time management by the designer can lead to delays in the implementation of the project. It is important that the designer has experience managing projects of similar scope and scale. The designer must be aware of the applicable laws and regulations related to the implementation of the project. Improper compliance can lead to legal and financial consequences.

On the basis of the research and analysis carried out, measures are proposed for decision-makers and tendering institutions to increase the efficiency and safety of the designer selection process. It is recommended to implement a pre-qualification stage, which will allow the competence of potential designers to be verified at the very beginning of the process. It is definitely worth paying more attention to qualitative criteria in the evaluation of bids than to price alone. It is also important to encourage designers to use compatible software and digital collaboration platforms to improve data exchange and coordination between participants in the construction process. At the contract signing stage, it is recommended to include penalties for delays, mandatory third-party liability insurance and a discussion with the designer about contingency plans in case of errors, changes or non-compliance with regulations. For procurement staff, it is recommended to organise regular training on tender evaluation, technical analysis and the risks involved in the selection itself. Implementing these recommendations can significantly reduce investment failures and increase the efficiency of the tendering process.

Choosing the right designer in a tender procedure requires a thorough financial, technical, schedule, legal and quality analysis. Only a comprehensive approach to risk assessment can ensure the success of a project.

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ANALYSIS OF MUNICIPAL WASTE MANAGEMENT PROBLEMS ON THE BASE OF THE SILESIA VOIVODESHIP ENTERPRISE

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Purpose: The main aim of the research presented in this article was identification and analyzation the logistical problems occurred in municipal waste management and their impact on their recycling in the context of sustainable development. Additionally, the proposing of several improvements that can increase the efficiency of the waste management system. Nowadays, through the newly emerging EU directives, the increasing population and consumer lifestyle, thus the huge amounts of generated waste, the problem of waste will increase, and it will be more important to find new solutions to encourage people for recycling.

Design/methodology/approach: In the research presented in this article, an analysis of the literature and Silesia voivodeship enterprise on the processes of waste management was used; with particular emphasis on the logistics of waste collection, segregation and sorting.

Findings: The analysis highlights the need for further technological modernization and continued educational activities aimed at society to achieve higher standards in waste management. The implementation of modern technological solutions and educational activities can significantly improve the waste management process, contributing to the implementation of sustainable development and minimizing the negative impact on the environment.

Research limitations/implications: Future research will be continued in the field of municipal waste management like collection, segregation, sorting, recycling and consumers' attitude.

Practical implications: The main objective of this article was to analyze the logistic problems related to municipal waste management from the perspective of a company providing comprehensive services in the field of waste collection and management. As part of the conducted research, key challenges were identified, such as insufficient waste segregation at source and lack of precision in sorting processes.

Originality/value: Based on empirical research, the article shows the scale of the problem that, through the new EU directives on the circular economy and sustainable development, will be a forward-looking and important issue. Additionally, the article presents concepts for waste management from the industrial and consumer perspective.

Keywords: municipal waste, recycling, waste segregation, sustainable development.

Category of the paper: Research paper.

1. Introduction

Municipal waste is one of the most visible and key challenges facing contemporary society. In an era of rapidly growing population and intensive urbanization, effective management of waste has become a priority not only at the national level, but also globally. Responsible waste management is crucial for environmental protection, public health and sustainable social development. Regardless of the source of its origin, appropriate processing and minimization of municipal waste are an important element of pro-ecological strategies that aim to reduce the negative impact of humans on the planet.

Municipal waste is waste generated in households, as well as waste of a similar nature and composition that comes from other sources, such as trade, services, educational institutions, public administration or health care. The definition of municipal waste can be found in many global, European and Polish laws. In Poland, the definition used is that "municipal waste is waste generated in households and waste from other waste producers, which due to its nature and composition is similar to waste from households, in particular unsegregated (mixed) municipal waste and selective waste" (Dz.U. 2013, poz. 21). An important aspect is that this waste does not come from manufacturing activities, agriculture or sewage treatment plants. The definition of waste based on applicable legal regulations was presented by Seroka-Stolka in her article, indicating that "waste is considered to be any substance or object which the possessor disposes of, intends to dispose of or is obliged to dispose of" (Seroka-Stolka, Ślusarczyk, 2022).

The development of technology and the changing attitudes of societies towards environmental protection in the 20th and 21st centuries have led to the further development of waste management systems. Currently, many countries are introducing advanced waste separation, recycling and energy recovery systems, which contribute to reducing the burden on the natural environment. In Europe, the history of waste management has undergone a significant evolution, especially in the 20th and 21st centuries, when countries began to introduce advanced recycling and energy recovery systems. Many European countries, including Germany and Sweden, have become leaders in the field of sustainable waste management, developing modern technologies and practices that reduce the burden on the environment (Zalewska, 2019).

In Poland, the development of the waste management system quickens after accession to the European Union in 2004. The introduction of regulations in line with EU directives significantly improved waste management in the country, especially in segregation and recycling. Poland is gradually increasing the share of waste subject to recycling and introducing innovative solutions, such as waste incinerators and energy recovery systems. However, despite progress, there are still challenges related to the full implementation of European standards, especially in smaller towns and rural areas. Further investment in infrastructure and

environmental education of society are key to achieving the goals of sustainable development and effective waste management in Poland (Dz.U. 2013, poz. 21; Wengierek, 2015).

2. Conceptual background

2.1. Municipal waste definition

Waste can be classified in many ways, but the simplest division concerns the place where it is generated. According to this classification, waste can be divided into industrial and municipal waste. The first of these is waste from industrial plants or factories. Municipal waste is generated by households or other places where waste with a similar composition is generated, e.g. offices or scientific institutions (Lipińska, 2016). To organize waste management, a waste catalog was created, considering its source, main components and properties. Municipal waste is described by using a 6-digit code, the first two digits of the code represent the waste group, the next two their subgroup, and the last two the type of waste. The 6-digit waste code in the catalog for municipal waste is 20 00 00 (Lutek, 2020; BDO, 2025).

One of the key assumptions in waste management is the waste hierarchy, defined by the European Commission (Figure 1). This hierarchy is the basis for sustainable waste management and defines priorities for actions aimed at minimizing their negative impact on the environment. Waste prevention comes first, followed by reuse, recycling, recovery (including energy recovery), and finally disposal, such as landfilling. This structure aims to promote actions that bring the greatest ecological benefits (EUR-lex, 2025).



Figure 1. Waste management hierarchy.

Source: epa.gov.pl

In waste management, proper classification of waste plays a key role, providing the foundation for effective segregation and further processing. Precise determination of the type and origin of waste is the first stage in the complex process of waste management, which enables effective use of recycling and disposal technologies. Due to proper classification, it is possible to redirect individual waste fractions to the appropriate processes, which minimizes their storage and maximizes the recovery of secondary raw materials.

2.2.The concept of waste management

In waste management, proper classification of waste plays a key role, providing the foundation for effective segregation and further processing. Precise determination of the type and origin of waste is the first stage in the complex process of waste management, which enables effective use of recycling and disposal technologies. Due to proper classification, it is possible to redirect individual waste fractions to the appropriate processes, which minimizes their storage and maximizes the recovery of secondary raw materials. The main goals of properly conducted waste management are: maintaining cleanliness and order, protecting the natural environment, economical management of raw materials and natural resources and economical management of land (Hordyńska, 2017).

The concept of waste segregation the allocation of waste to a given group, in which there is a material from which the waste is made. According to the definition contained in the book "Logistics of waste management: ecologist, municipal and medical waste", segregation is the process of selecting and separating waste according to specific features that this waste has. The segregation process itself can be divided into three groups: manual segregation, mechanical segregation and automatic segregation.

The first of them is segregation consisting of separating components that allow for reuse. It is segregation of materials such as: glass, paper, plastics or steel. This segregation is performed by company employees using specialist machines not adapted to this segregation. Mechanical segregation is performed by machines located in the factory; such segregation is performed for two fractions:

- Heavy fraction (metals, glass, stones, rubble, organic and biological parts).
- Light fraction (plastic, paper, textiles).

In this part of the segregation, reuse is not used, which is the biggest difference between the first two segregation groups. In automatic segregation, mixed waste is segregated by its properties (Sidelko, 2017).

Waste segregation plays a fundamental role in sustainable waste management and environmental protection. It enables the effective separation of raw materials that can be reused from those that require disposal. Thanks to proper segregation, waste is directed to the appropriate treatment processes. Waste treatment is a key element of modern waste management, the aim of which is to minimize the negative impact on the environment and to

use resources efficiently. This process includes various technologies and methods that allow waste to be transformed into secondary raw materials, energy or other products suitable for reuse (Rozporządzenie 1, 2018).

Waste processing reduces the amount of waste going to landfill, which limits the emission of harmful substances and supports the development of a sustainable economy. Waste processing is understood as the process of recovery or disposal, including preparation prior to recovery or disposal. If waste does not go to landfill, it can be subjected to various processing methods, such as (Bauman-Kaszubska, 2017):

- Incineration.
- Gasification.
- Composting.
- Melting.
- Shredding.
- Fermentation.
- Compaction.
- Recycling.
- Separation.
- Use in agriculture.
- Chemical processing.

Of the listed methods, the most well-known and commonly used methods of waste processing are recycling, composting and incineration. The recycling process involves reprocessing waste into new products. The subject of recycling can be various wastes, including machines or devices that are no longer suitable for use. The definition of recycling includes the reprocessing of organic material (so-called organic recycling) but does not include energy recovery or the processing of materials intended for fuels or for filling excavations.

Recycling plays an important role because it allows the reuse of raw materials, which has a positive impact on the environment. The following types of recycling can be distinguished (Świątkowska, 2017):

- By type of waste:
 - Raw material - involves processing waste into raw materials that can be reused to produce a given product.
 - Material - converting waste into new products with a similar use.
 - Energy - processing waste into energy fuel that can be used to generate energy.
- By degree of processing:
 - First-degree recycling - reuse of entire, homogeneous products.
 - Second-degree recycling - recovery of parts or elements from used products.
 - Third-degree recycling - recovery of individual materials that the waste contains.

The second use of waste is composting. This is a process in which dead organic matter occurs, made available using microorganisms in use. This can be understood as organic packaging. We use it to create compost, which is available for the use of natural fertilizers. Composting the main key in waste management, according to Rosik-Dulewska, composting must take precedence over waste storage in a landfill or other method of disposal (Rosik-Dulewska, 2015).

Another popular processing method is waste combustion. Waste combustion is used for materials that cannot be reused. This process allows energy to be generated by burning them, which allows energy to be recovered in the form of heat or electricity. Waste processing is a key element of modern waste management, which includes various methods aimed at efficient use of resources and minimizing negative impacts on the environment. Recycling, composting and waste incineration are just some of the available methods for converting waste into secondary raw materials, energy or products ready for reuse. Each of these technologies plays a significant role in reducing the amount of waste going to landfills, reducing harmful emissions and supporting the development of a sustainable economy. Implementing effective waste processing processes is therefore a necessary step towards a more ecological and responsible resource management society that strives for maximum recovery of raw materials and minimizing negative impacts on the natural environment.

2.3. IT systems and technologies related to the municipal waste management

IT systems are a very important aspect in waste management, which aim to optimize the management of processes related to their collection, transport, segregation and recycling. The requirements that local government units must meet are specified in the Act of 13 September 1996 on maintaining cleanliness and order in municipalities, some of them were shown in Figure 2. Waste flow management includes procedures such as:

- Waste management planning.
- Waste collection.
- Calculation of fees.
- Waste storage.
- Waste disposal.

The Internet is the most important in waste management, as it interacts with the systems and technology found in companies. The database of products and packaging and waste management is a system based on Internet technology, enabling effective management of information related to waste management. This register came into force in 2012, where it replaced the paper version of the register with an electronic one. Mobile applications are becoming increasingly popular these days, which are used to remind residents about waste collection, and indicate which waste is being collected (Brzeszczak, 2017).



Figure 2. Selected requirements of an IT system for waste management.

Source: own work based on: Brzeszczak, 2017.

In waste management technology, various methods of waste identification are used. One of this method is barcodes, which act as an identifier, allowing reading of specific information about a given waste. Marking waste with barcodes significantly increases the efficiency of the waste management system, while also enabling control and monitoring of selective collection.

Due to automatic data entry into IT systems, the risk of errors made by employees is eliminated. Another method used in waste marking is RFID technology, which involves the use of radio waves to send information. RFID technology is also used in waste management, which uses radio waves to record and read information, which allows for quick and effective tracking of waste. The last method that can be encountered is the use of GPS systems, which involve monitoring vehicles transporting waste or containers. Technologies and systems enable continuous improvement and monitoring of waste management, which allows for more precise segregation and recycling, supporting sustainable development. Additionally, they support environmental protection and increase the effectiveness of the entire waste management system (Chomiak-Orsa, 2016; Małachowski, 2019).

3. Problems with municipal waste management in selected enterprise

The municipal waste industry is one of the key sectors of the economy, having a significant impact on the natural environment and the quality of life of residents. According to data from the Central Statistical Office, a total of 53 658 686.95 tons of municipal waste was collected in Poland in 2020–2023, which is presented in Figure 3 illustrating the amount of waste in individual years.

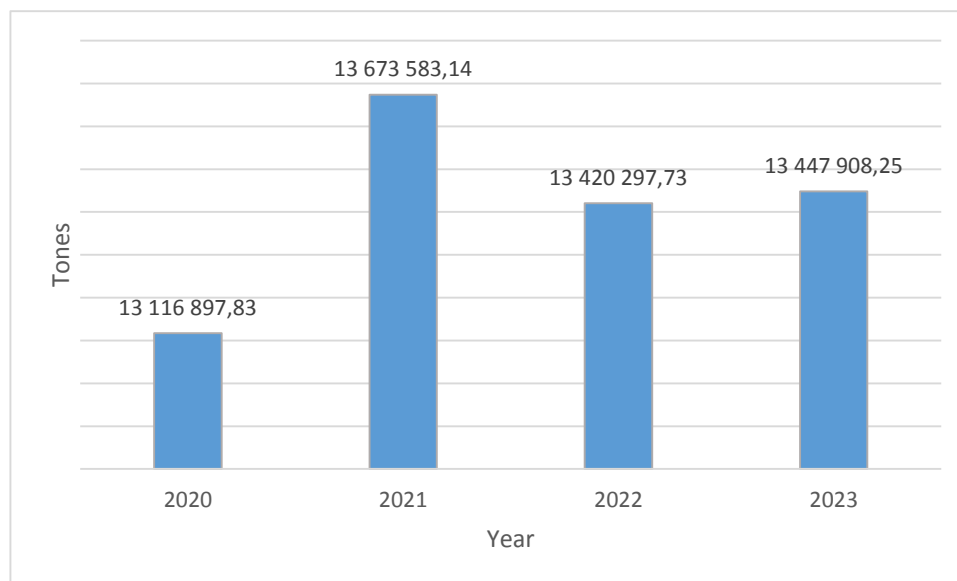


Figure 3. The amount of collected municipal waste in Poland in 2020-2023.

Source: Own work based on: Stat.gov.

Data analysis indicates a general stabilization of municipal waste in recent years, but it still occurs at a relatively high level. Such information provides valuable information on the challenges related to waste management. In addition to the total amount of waste, the level of waste segregation is also important, which directly affects the productivity of recycling and recovery of raw materials. Another important aspect is the ratio of the amount of waste collected selectively to the total amount of waste. Figure 4 shows the percentage share of waste collected selectively in relation to the total amount of waste in 2020-2023 in all of Poland.

The analyzed company is a Polish municipal company located in the Silesia region, which holds 90% of the shares, while the remaining 10% belongs to the municipalities co-creating the waste management system, such as Łędziny, Chełm Śląski etc. As a municipal company, it cooperates with local governments, implementing tasks resulting from legal regulations, as well as supporting activities related to environmental protection. The company also conducts educational activities aimed at raising ecological awareness among residents and promoting sustainable practices in waste management.



Figure 4. Percentage share of selectively collected waste in relations to the total amount of waste in 2020-2023.

Source: own work, based on: Stat.gov.

The company specializes in comprehensive waste management, including collection, transport, segregation and management of municipal waste. A key element of the activity is the implementation of modern technologies, such as raw material and energy recovery systems, which supports the implementation of sustainable development assumptions. Waste collection is carried out both from households and public entities and companies operating in the service area.

3.1. Analysis of disruptions related to waste collection and transport

Transport and logistics are key aspects of the functioning of any business, especially in the waste management industry. They include activities such as developing schedules, optimizing routes and managing vehicle fleets. The efficiency of these processes directly affects the quality of services provided and operating costs.

One of the most important problems in logistics is the difficulty of adapting schedules to dynamically changing operating conditions. Unforeseen situations, such as vehicle breakdowns, difficult weather conditions or road blockages, can lead to disruptions in the implementation of waste collection plans. Such disruptions not only increase operating costs, but also reduce the efficiency of the company's operations, which can negatively affect customer satisfaction and compliance with legal regulations.

An additional challenge is the short time allocated for developing logistics schedules, which increases the risk of making mistakes and introducing less optimal solutions. As a result, this can lead to inefficient use of resources, increased transport costs and reduced quality of services provided. Effective management of logistics processes therefore requires the implementation of modern technologies, such as GPS monitoring systems and advanced route planning software, which enable faster and more precise decision-making.

3.2. Analysis of disruptions related to segregation and consumers' attitude

Another very important problem in waste management is ensuring effective segregation, both at the place of their generation and at the stage of processing in recycling plants. Source segregation, carried out by residents and companies, is a fundamental element of recycling and raw material recovery processes. Proper sorting at the stage of waste generation allows for increasing the efficiency of the entire waste management system, but the lack of environmental awareness in society and improper segregation practices can lead to a decrease in the quality of secondary raw materials obtained. Mixed or improperly segregated waste is more difficult to process and often requires additional cleaning processes, which generates higher costs and increases the time needed to prepare it for recycling.

At the processing plant level, precise waste segregation is equally important, which is carried out using manual and mechanical sorting. Manual sorting, despite the involvement of employees, often does not allow for the detection of all unwanted elements due to the limitations of human perception and fatigue. This can reduce the efficiency of the process and lead to contamination of the obtained fractions. In turn, mechanical sorting, using advanced devices such as optical, electromagnetic or vibration separators, allows for more precise separation of individual types of materials. Nevertheless, even the most modern technologies are not able to eliminate the risk of failure to detect small or specific elements, such as foils, textiles or multi-material elements.

An additional challenge is the need to adapt segregation and sorting systems to increasingly diverse waste resulting from the development of new technologies and changes in society's lifestyle. Introducing new products to the market, such as multi-material or biodegradable packaging, requires continuous modernization of infrastructure and development of innovative separation methods. Effective waste segregation management also requires educating the public about ecology and improving awareness of the principles of proper sorting. Information campaigns, training programs and appropriately designed incentive systems can significantly contribute to improving the quality of segregation at source.

At the same time, investments in modern sorting technologies and optimization of processes in processing plants are necessary to meet the growing requirements for the recovery and recycling of raw materials. The process includes monitoring the implementation of the level of over 55% recycling, in accordance with applicable European standards. In the event of failure to achieve the assumed goals, data on the causes is collected. The management team in the examined enterprise, consisting of 8 people, analyzes the collected data, identifies problems and implements corrective actions. The effectiveness of these actions is regularly monitored and assessed. In a situation where the actions bring the expected results, the process ends with success and the secondary raw materials are directed to recirculation. However, in the absence of satisfactory results, the process again moves on to the analysis of problems and development of new solutions. Unfortunately, in 72% of cases, the waste does not meet the required level of

recycling specified by European standards. Only 18% of waste reaches the required level of recycling, which indicates a very low level of waste segregation at source, and at the same time, this is a potential area for improving the current situation. Analysis of these cases indicates that to achieve success, good segregation at source and the potential use of modern sorting and recycling technologies must occur.

3.3. Analysis of disruptions related to technologies

Technological problems in waste management constitute a significant barrier to effective waste management and the achievement of circular economy goals. One of the most serious challenges is the lack of appropriately developed waste processing infrastructure. In many cases, waste disposal and recycling plants are not sufficiently equipped to effectively process various waste fractions, such as multi-material waste, electronics or biodegradable packaging. The shortage of thermal waste treatment facilities and mechanical-biological treatment plants leads to a significant portion of waste being redirected to landfills, which is contrary to the principles of sustainable development.

Equally problematic are the technological difficulties associated with waste segregation and sorting. Manual sorting, although still widely used, is time-consuming and error-prone, which reduces its dynamics. On the other hand, mechanical sorting, even when using advanced technologies such as optical, electromagnetic or vibration separators, has its limitations. It is particularly difficult to separate multi-material elements, small plastic fragments or organic waste, which negatively affects the quality of the secondary raw materials obtained. Another problem is the limited efficiency of recycling technologies. Contaminated waste, materials that are difficult to separate, such as multi-material packaging or low-quality plastics, are often not properly processed. In the case of some materials, such as PVC or polyesters, chemical recycling requires expensive and advanced technologies that are still not widely available.

The implementation of advanced technologies such as robotics, artificial intelligence or data analysis, which could revolutionize waste management, encounters barriers related to high implementation costs and insufficient staff training. Modern waste sorting robots, predictive systems for waste stream management or real-time monitoring technologies remain rare, especially in smaller enterprises. Modernization of technology also requires huge financial outlays, which is a significant challenge for many enterprises and municipalities. The costs associated with the purchase of modern machinery, construction of processing installations or implementation of monitoring systems often exceed the financial capabilities of local communities. As a result, technological limitations in waste management become a serious obstacle to the effective functioning of waste treatment systems, which negatively affects both the environment and the implementation of sustainable development policy goals.

4. Proposals for improvements to problems identified in the enterprise

4.1. Improving the process related to waste collection and transport

Very significant problem in the waste management process is the insufficient segregation of waste at its source, which significantly affects the efficiency of subsequent stages. To prevent the continued occurrence of this problem, it is crucial to introduce more readable and easily accessible information materials that will contain detailed segregation rules. Information materials should be designed in a simple, clear and intuitive way, so that the segregation rules are easy to understand for various social groups, including children, seniors and people less involved in environmental protection. One practical solution in this area is the introduction of information systems on containers, such as QR codes, which allow for quick scanning using a smartphone and obtaining detailed instructions on segregation. Because of this, users will have access to up-to-date, detailed information at any time, which will significantly facilitate proper waste management.

To increase the effectiveness of the activities, the materials should be available in various communication channels, such as social media, local press or educational meetings organized in schools and public institutions. Combining traditional educational materials with modern technologies, such as information systems on containers, will allow reaching a wide audience and significantly contribute to building ecological awareness in society.

4.2. Improving the process related to waste segregation and consumers' attitude

The key challenge related to improving the waste segregation process is the lack of motivation of customers to properly segregate waste. One of the proposed improvements is the implementation of a system of incentives for customers, e.g. offering discounts on waste fees if a given locality collects an appropriate amount of waste that meets the standards of proper segregation. This type of motivational mechanism can increase the involvement of residents, which will directly affect a higher level of recycling and a better quality of processed waste.

An additional step to improve the waste management system could be the introduction of regular communication with residents, to inform about the results of segregation in their region and the impact of their actions on the environment. Highlighting successes and achieved results can significantly increase the sense of responsibility and motivation of residents to improve the quality of segregation. One of the innovative solutions could be a mobile application that would present the level of waste segregation in real time on specific streets of a given town, allowing residents to access information about the quality of segregation in their area and compare results with other streets. The application could also include features such as a notification system reminding about the waste collection schedule, segregation rules, rankings and statistics of the best segregation results among streets, as well as a reward system for residents who achieve a high level of segregation in their region, which would additionally motivate them to take pro-

ecological actions. In that application could also be a platform through which residents could report problems related to waste collection or suggest improvements in the waste management system. Integration of modern technologies into the communication system with residents would not only increase their involvement but also allow for more transparent and effective waste management on a local scale.

4.3. Improving the process related to technologies

The problem of inaccuracy in sorting can occur in the entire process in two cases. The first concerns mechanical sorting, which is carried out using sorting machines. The second case is manual sorting performed by employees, which is a time-consuming and less precise process.

To improve the waste sorting process, a gradual process of modernization of the sorting plant can be introduced. One solution is the use of sorting robots equipped with an advanced identification system, such as artificial intelligence. These robots can segregate waste faster and more accurately compared to human work.

The use of robots will not only improve the precision of sorting but will also allow for a reduction in the number of employees involved in manual sorting. The number of employees could be reduced to one person who will monitor the work of the robots, eliminating tiredness and human errors that often occur in the case of long-term, monotonous tasks.

In addition, the introduction of robots in sorting plants would contribute to increased safety at work, eliminating the risk of employees meeting hazardous waste. Automatization of the process could also reduce operating costs in the long term, as the investment costs in robots can be recouped through greater sorting efficiency and higher quality of recovered raw materials. The introduction of advanced technologies will significantly improve the waste segregation process, while increasing safety and work efficiency. These technologies will also enable more precise segregation, which will directly contribute to increasing the level of recycling in the entire process.

5. Summary and conclusion

The main objective of this article was to analyze the logistic problems related to municipal waste management from the perspective of a company providing comprehensive services in the field of waste collection and management. As part of the conducted research, key challenges were identified, such as insufficient waste segregation at source and lack of precision in sorting processes. The implemented solutions, including automation of sorting using modern technologies and implementation of educational campaigns, allowed for a significant improvement in the quality of segregation and increased recycling efficiency. The obtained results indicate that the modernized waste management system contributes to lower operating

costs and increased recovery of secondary raw materials, which supports the assumptions of a circular economy. These results confirm that appropriate logistics management, supported by technologies and educational activities, can significantly increase the efficiency of the entire system. The amount of waste collected selectively in 2022 decreased by 3.0% compared to 2020 and amounted to 763.1 thousand tonnes, i.e. 44.5% of collected municipal waste (in 2020 – 44.2%). 93.5% of waste collected selectively came from households (92.1% in 2020). The waste most frequently selected by households includes biodegradable (biodegradable) – 35.6%, bulky – 15.0% and glass – 11.9% (US, 2022).

Based on the literature and the research the following conclusions can be drawn:

- Literature analysis provided detailed knowledge on the structure, classification and functioning of the municipal waste management system. Detailed familiarization with the legal regulations in force in Poland and the European Union enabled understanding of the key challenges related to waste management.
- A key element in the waste management system in the examined enterprise is the precision of sorting, both at the stage of waste segregation by customers and during its processing at the plant.
- Process analysis indicates the need for continuous improvements to meet the growing requirements and challenges in waste management.
- The introduction of educational activities, such as information campaigns, financial incentive systems for residents and clear information materials placed on containers, significantly improved the quality of waste segregation at source and increased residents' motivation to properly handle waste.
- One of the proposed improvements was the implementation of automatization of the sorting line, using sorting robots, which increased the precision and speed of waste sorting. The use of modern technologies contributed to reducing the time of segregation and reducing the number of employees involved in waste sorting.
- Another improvement was the proposal of an application that would enable better contact between residents and the company responsible for waste collection, and the markings on containers and QR codes provided detailed information on the principles of segregation, which translated into an improvement in the quality of sorting at source.
- By implementing the proposed improvements, the level of waste recycling would be higher, and the number of people involved in waste sorting would be lower, which would allow for reducing the company's expenses on employment.

The analysis highlights the need for further technological modernization and continued educational activities aimed at society to achieve higher standards in waste management. The potential of using modern tools supporting source segregation and increasing the effectiveness of recycling was also indicated. The implementation of modern technological solutions and educational activities can significantly improve the waste management process,

contributing to the implementation of sustainable development and minimizing the negative impact on the environment.

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DETERMINANTS OF EFFECTIVE SCIENCE–BUSINESS COOPERATION IN BIOTECHNOLOGY

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Purpose: The purpose of this article is to identify conditions favorable effective cooperation agile companies with institutions scientific in the sector biotechnology. Analysis submitted meaning attributes organizational agility in the context of building permanent Relationship science – business.

Design/methodology/approach: Applied approach qualitative in the form of a case study, focusing myself on analysis cooperation PROTEON PHARMACEUTICALS SA with the University of Technology Lodz. The data was collected on on the basis of structured intelligence questionnaire conducted with a representative management enterprise.

Findings: Cooperation with the university higher Maybe to be effective provided existence Relationship based on trust, complementarity resources, flexibility operational and common orientation on Implementation innovation. Agility organizational companies it favors initiating and maintaining effective relations with the sector science.

Research limitations/implications: Limitation research is his disposable and quality character, based on analysis one case, which limits possibility generalizations results. No triangulation data Maybe to influence on subjectivity conclusions.

Practical implications: Conclusions they can constitute basis for design effective models cooperation with universities in the sector biotechnology. Article indicates specific mechanisms and attributes organizational, which They support partnerships scientific and industrial.

Social implications: Strengthening Relationship science - business contribute to accelerate transfer knowledge and innovation, increasing employment high qualified Staff and Improvement competitiveness economy based on knowledge.

Originality/value: An original theoretical model was developed cooperation agile companies with a university higher, which integrates perspective practical with assumptions theory organizational agility. Article he brings new value for discussion over cooperation science and business in the condition's uncertainty and dynamic changes.

Keywords: agile enterprise, institutions scientific, biotechnology, cooperation, theoretical model.

Category of the paper: research paper.

1. Introduction

Contemporary companies biotechnological they operate in dynamic and turbulent environment surroundings. Key meaning is gaining skill cooperation with institutions scientific. Complexity processes research and development, high costs innovation and necessity fast reacting on changes market and technology they make effective cooperation science with business it stands myself condition necessary for development. In this in context special meanings is taking agility organizational. It enables She flexible and responsive management knowledge, relationships and resources.

The aim of this article is to identify factors favorable cooperation agile companies' biotechnology with the university higher, on example PROTEON PHARMACEUTICALS SA and rate values this one cooperation in the context of practices organizational and building advantages competitive. Article contains review literature, description Methodology research qualitative, analysis case, comparison with the results others research and wording recommendations. The value-added publication is an original model of cooperation. It can be practical tool supporting building Relationship science - business in reality economy based on knowledge.

1.1. Conditions functioning companies in the area biotechnology

Conditions functioning companies in the area biotechnology they characterize myself high degree complexity, uncertainty and risk, both on level operational and strategic (Eslami, Jungbauer, 2024). Companies these they operate in the environment strongly regulated, in which requirements formal, norms quality, processes Certification and restrictions legal they influence directly on the pace of introduction innovation and possibility of their commercialization (Mu'azzam et al., 2024). High threshold Entry on market, resulting from expensive research laboratory, necessity conducting long-term tests, and also requirements regarding safety and ethics (Anyanwu et al., 2024), makes development biotechnology is the domain of organizations that they have appropriate background capital, technological and competence (Javanmardi et al., 2024).

Important element the environment of biotechnology companies is strict interdependence with the sector science. It is also important necessity transfer results research basic for applications industrial. In practice this means that companies functioning in this sector they must constantly stay in touch with universities and institutes research and networks innovative. Through this they provide myself access to the latest knowledge, infrastructure and high qualified staff (Hojeij, 2024). Cooperation with the sector scientific constitutes therefore condition necessary for permanent development and maintenance advantages competitive (Afolabi et al., 2024).

Dynamic development technology (including development Engineering genetics, bioinformatics, diagnostics molecular Whether bioprocesses production) forces on company's big flexibility organizational and before ability to quickly adaptation (Afolabi et al., 2024). Changes in the environment market, emergence myself new threats health and environmental pressure on balanced development and growing expectations social regarding transparency and responsibility of actions, cause that companies biotechnological they have to invest in innovations as well shape culture organizational (Vojnovic et al., 2024; Nath, 2024). The latter has to to favor cooperation, openness and continuous learning (Mehta et al., 2024; Li, Duan, 2025).

Additionally, a challenge it remains access to financing activities research and development. This access to a large extent is largely dependent on instruments public and private sources capital high risks (de Moraes et al., 2024). In this perspective important it stands myself skill design and implementation common projects with institutions scientific. Equally is also important skill preparation applications within programs national and international. Programs these They support innovation and research applied (Mu'azzam et al., 2024). Contemporary companies biotechnological They function therefore on contact science, economy, technology and politics public. However, it requires from them developed competence management relationships, projects interdisciplinary and wallets innovation (Javanmardi et al., 2024; Fei et al., 2025).

In the conditions Yes strong dynamics and multidimensionality surroundings, more and more bigger meanings is taking agility organizational. Means She ability to quickly reacting on changes, identification chances market and transforming knowledge scientific into real solutions product and process (Wasyleczko et al., 2024). Enterprises biotechnological, which they want remain competitive and effective implement innovations, must to develop own resources technological, but simultaneously too they should strengthen your own ability to cooperate, adapt and integrate scattered sources knowledge (Li, Duan, 2025; Mehta et al., 2024; Arnold, 2024).

1.2. Agile attributes companies' favorable cooperation with institutions scientific

In terms of dynamic and complex the environment in which it came function to companies biotechnological, special meanings they are taking these attributes Agility organizational, which They support effective cooperation with institutions scientific (Shi et al., 2023). Agility, understood as ability to quickly reacting on changes, and at the same time predictions trends and flexible customization to the new ones conditions, manifests among others in the way initiating relationships, management knowledge and integration resources within intersectoral projects research and development. An important attribute is the proactivity of the company (Plotnikov et al., 2024). This feature means that undertaking actively I am looking for partnerships and co-creation agenda research with universities (Ju et al., 2020). Organizations distinctive myself high level autonomy decision-making and openness on new ideas faster They

identify potential areas cooperation. In addition, efficiently they turn them into action in line with the goals both both scientific and commercial (Omowole et al., 2024; Sharma et al., 2022).

As the ability to quickly is important taking up decisions. It is also important Moreover Ready for testing new solutions (Claudhary, Trzecieliński, 2021; Olszewski, 2023). This is especially important in the phases early research and prototyping, which they bind with a lot uncertainty about the effects finals (Andriyani et al., 2024). These companies that they can flexibly to manage risk and use approach iterative in implementation projects, they show bigger effectiveness in relationships with partners (Zhao et al., 2022). Such cooperation requires skills implementation new technology and openness on corrections and improvements in progress implementation common goals (Kocot et al., 2023; Wahab et al., 2024; Mishra et al., 2021; Sharma et al., 2022). It is necessary to have on in view of the fact that agile organizations are part of networks interdependence in which flow knowledge, open communication and integration external resources are the foundation of long-term cooperation (Thomas, Suresh, 2023). In this in context especially important it turns out myself culture organizational, which is based on trust, willingness to cooperate and respect for competence partner. Such a culture it favors building interdisciplinary teams research and implementation (Claudhary, Trzecieliński, 2021).

The next one a distinguishing feature agile the company is flexible structure organizational (Plotnikov et al., 2024; Wahab et al., 2024). It allows She on fast creation teams task-oriented and efficient allocating resources, depending on the changing myself needs design. Such adaptability operational allows on more effective Implementation results research (Omowole et al., 2024; Plotnikov et al., 2024). It enables also their current adaptation to conditions technological, market Whether regulatory. Enterprises capable of fast reacting and reorganizing in response on variables factors external they gain advantage in cooperation with universities (which also are subject to pressure design and institutional) (Brendzel, 2023; Ju et al., 2020).

Not to be underestimated it remains also ability to absorb knowledge. Such ability means skill identifying, assimilating and practical use results research conducted outside the organization (Shi et al., 2023). In this take school it stands myself active partner in the process Creating innovations that they can to be implemented in the form of new products, processes or models management. The ability to transform knowledge scientific solutions market shows high level maturity organizational and position companies in the system innovative. Only organizations agile, which are Open on sharing competence and ready for continuous learning they will be able to fully to use potential cooperation with the sector science. They will be probably create from it real value added (Zhao et al., 2022; Mishra et al., 2021; Kocot et al., 2023).

1.3. Conditions effective cooperation enterprises and institutions scientific in the area biotechnology

Effective cooperation between companies and institutions scientific in the area biotechnology requires fulfillment specified conditions. They go beyond formal partnership and include compatibility goals, complementarity resources and ability to work together creation and implementation knowledge (Subha et al., 2024; Xue, 2025). Key has strategic importance approach both pages, based on mutual trust, openness on teaching and willingness to share Risks and results. Report science - business she should to be perceived as process long term. It requires a joint defining goals research and implementation and mechanisms of their implementation (Javanmardi et al., 2024).

In the conditions specifics biotechnology, where processes innovative are expensive and time-consuming, it is necessary to develop both pages competence coordination, flexibility operational and abilities absorption (Hojeij, 2024; Vráblová et al., 2024). Cooperation she should include both Actions experimental and implementation. They are supported by appropriate instruments management projects and mechanisms translation knowledge scientific on Tongue applications market. It is also essential assurance clear legal and institutional framework. They promote transparency of activities, protection property intellectual and Equality pages (Afolabi et al., 2024). Efficiency cooperation depends also from presence external ecosystem supporting innovations (including system financing, institutions intermediaries and policies public promoting partnerships scientific and industrial). Only in such conditions That's possible it stands myself building permanent Relationship intersectoral, which They translate myself on real innovation and competitiveness companies biotechnological (Durand, Hassan, 2024). In addition to the concept of organizational agility, it is worth referring to the theory of open innovation and absorptive capacity. Open innovation assumes the active acquisition and use of external knowledge, including through cooperation with universities. This promotes the creation of joint solutions. In turn, absorptive capacity refers to the ability to identify, assimilate and apply external knowledge in practice. Both concepts help to better explain how science-business cooperation can lead to lasting innovations in the biotechnology sector.

2. Methods

The purpose of exploration research was deepened recognition conditions favorable effective cooperation between institutions scientific and business operating in the sector biotechnology, which shows characteristics agile, and which you can define as organization agile. Intention researchers was capture dependence between dynamics this one cooperation and ability companies to generate innovation, adaptation to the changing myself surroundings and building long term advantages competitive.

Point exits for conducted analysis was hypothesis assuming that effective cooperation between sector science and agile enterprise biotechnological he is leaning myself on flexible approach to common goals, mutual trust, complementarity resources and readiness to share myself responsibility and risk within common ventures research and development.

Within the framework of Exploration formulated following questions research: (1) What forms is gaining cooperation between the company biotechnological and the unit science and how it evolves she in time? (2) What factors institutional, organizational and interpersonal they are conducive efficiency this one cooperation and what I limit? (3) In what way way cooperation with science it affects on development innovative products, technologies and processes in the enterprise biotechnological? (4) What role in this in the process plays exchange knowledge, resources human and infrastructure research? (5) Is cooperation with the university higher is seen as an element of long-term strategy development organizational and technological enterprises?

The above questions they served as frame analytical for interpretation content obtained as a result qualitative interview with a representative management companies Proteon Pharmaceuticals SA Empirical data They were obtained on the basis of a structured interview questionnaire, which he was left forwarded to management companies Proteon Pharmaceuticals SA Answers granted They were By person managing , having detailed knowledge on topic activities operational and strategic companies, including also on topic the previous one cooperation with institutions scientific and research, especially with the University of Technology Lodz.

Research questionnaire He was folding myself total of 20 questions. 13 questions It had character closed (with answers one-time or multiple choice), while 7 gained form open, enabling development answers and presentation opinions, experiences and suggestions. Questions Closed They served categorization data and ensuring comparability answers in terms of quantitative, while questions Open made it possible Exploration qualitative aspects cooperation, subjective evaluations and reflections regarding relations with the sector science.

Range thematic questionnaire included five main areas: characteristics organizational companies (profile activities, employment, facilities R&D), history and scope cooperation with institutions scientific, forms being carried out projects research, involvement in initiatives educational and conference, as well as assessment the previous one cooperation and proposals for its improvement. In particular included questions regarding time duration cooperation with the university, sources of its initiation (or it was an initiative universities, companies, or another entity), purposes original and current, scope cooperation (research, implementation, work diploma, licensing), and also expectations in relation to potential benefits flowing from commitment students and young scientists in the field companies.

Collected material empirical he was left subject qualitative analysis content. Its purpose was isolation the most important determinants of effective cooperation between science and the sector business. This analysis made it possible Identification both factors both supporting and barriers limiting development Relationship intersectoral, in the context of industry biotechnology, having on in view of the fact that This industry is characterized by myself high dynamics changes, risk technological and requirements regulatory. At the same time, it is possible was recognition characteristic features model organizational examined companies that shows marks agility – including ability to be flexible shaping relationships with partners external, fast reacting on needs market and Integration knowledge from various sources in the process creation innovative solutions.

3. Results

Analysis of results intelligence questionnaire conducted with the management companies Proteon Pharmaceuticals SA allows to capture important problems and dependencies regarding cooperation companies' biotechnology with the institution scientific - University of Technology Lodz. Each of the raised issues is treated as a separate research problem which in a relevant it affects on quality, intensity and durability cooperation on contact science and business (see Figure 1). Figure 1 shows eight key areas cooperation companies Proteon Pharmaceuticals SA with the institution scientific - University of Technology Lodz (identified on on the basis of analysis intelligence questionnaire). At most rated They were Three aspects (value 4 on a scale of 0-4), i.e. profile and specialization companies, facilities R&D and the need cooperation, and character and motivations for cooperation. Values 3 were assigned such areas such as: effects cooperation and barriers financial, forms and continuity cooperation, cooperation Educational and HR and possibilities development model cooperation. The lowest rated connections cross-sectoral (value 2), which can to indicate on area demanding further reinforcements. Fig. 1 allows to illustrate which elements cooperation are strong side

Relationship science - business, and which ones whereas they require further development or support systemic.

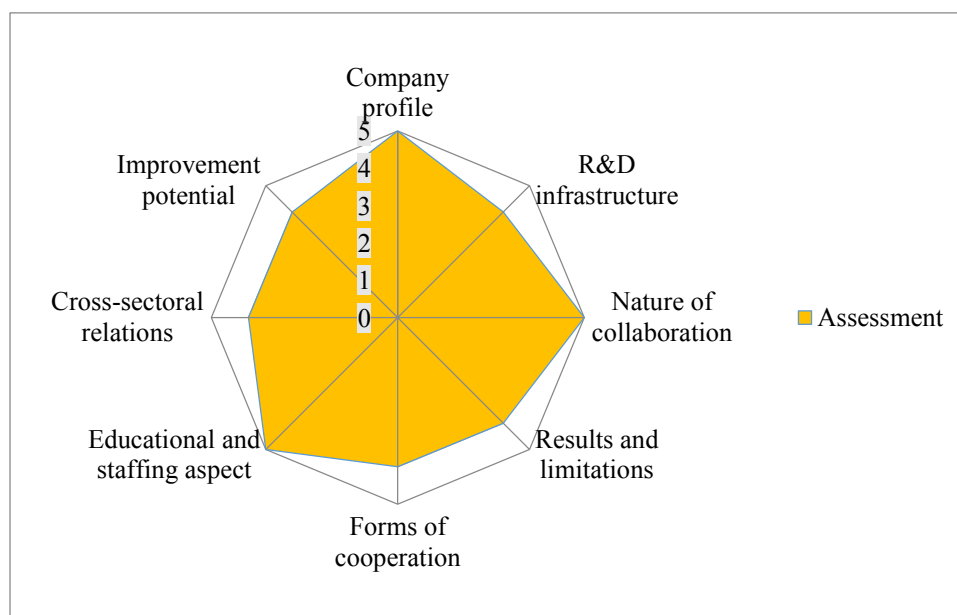


Figure 1. Area's analysis cooperation companies Proteon Pharmaceuticals SA with the institution scientific.

Source: Prepared by own.

The first a problem subjected the exploration is the identity and scope activities analyzed enterprises. Determination the organization profile allows to assess, on How many activity given companies it holds in the sector biotechnology, and also whether its functioning requires advanced support scientific. Proteon Pharmaceuticals SA is an organization fully rooted in biotechnology, with high level specialization, concentrating myself on research over bacteriophages and the creation of advanced preparations biological. Such a profile activities determines the necessity maintaining relations with the sector science, mainly in the field of conducting analysis, implementation innovation and testing effectiveness solutions.

The second the problem that emerges from the analysis, there is a question backroom research and development companies. Answer granted by management companies clearly indicate that Proteon Pharmaceuticals has own, good developed R&D facilities. This statement leads to the key questions, or possession such backroom weakens need cooperation with universities. Answer to this question it turns out myself complex. On one pages undertaking he can independently to lead significant Hi wash research and implementation. On the other hand, on the other hand, he notices need cooperation with units scientific. First of all, it is clearly visible in the areas that they go beyond apart from my own expertise technological or they require specialized infrastructure and competences external.

The third problem concerns character cooperation with institutions scientific and motivation to establish it. Answer indicates that cooperation with the University of Technology Lodz she was initiated by itself company and at the same time initiated by implementation doctorate implementation. This relationship included initially character individual. Then she expanded myself on commissioning specific research and licensing material biological. This indicates a model of cooperation based on trust, long-term and fit substantive. The problem research, which here myself appears, there is a question about the extent to which to a degree initiative and commitment companies are condition necessary start cooperation with the university. It is also interesting how the universities they answer on needs reported by business.

Another problem is related to the effects the previous one cooperation and its evaluation. Proteon Pharmaceuticals positively I am evaluating the previous ones relations with the University of Technology Lodz, considering that every time they led to the achievement intended goals. This observation raises but important the issue limitations. Barrier, it turns out myself lack sufficient financing some initiatives research, independent of good will pages. This problem shows structural the challenges that often NO they concern quality the relationship between science and business, but systemic support financial for innovation and research industrial.

Next a significant problem concerns scope and forms of cooperation. Enterprise emphasizes that cooperation with the university she had various nature: from implementation research on order, by cooperation over specific products, up to education and development staff. Answer provided indicates also, that business NO it leads Currently common projects research with the university. Maybe raise this question of continuity cooperation and the conditions for its re-intensification. This problem is directed attention to whether or not cooperation is of a nature project and cyclical, or is also embedded in the long-term strategy both institutions.

It is also interesting meaning cooperation in the context of Educational and HR. Management companies clearly indicate on significance relations with students and graduates Polytechnics Lodz. Employment many of them, including people associated with the company from the beginning activities in the area bacteriophages, proves that school full function Suppliers high qualified staff. This problem opens up a field for reflection over whether and in what way in scope cooperation with universities full function capital investment human, not only in solutions technological.

A separate problem concerns connections intersectoral, including cooperation with administration and institutions support innovation. Proteon Pharmaceuticals indicates on necessity integration knowledge and infrastructure from various sources (also from outside sector strictly biotechnological). In this in context the role of institutional partners, such as agencies, is highlighted regional. Their share Maybe support complex development products. This raises the question of how to a degree institutions surroundings business are active intermediaries and animators' cooperation scientific and industrial. And in what on the other hand are only passive participants ecosystem innovation.

The last one analyzed problem refers to model direct cooperation and possibilities his improvements. Although formal cooperation model he was left worked out, appears myself reflection that it is possible enlargement on new areas. This applies to areas procedural, not Just product and research. This statement allows to formulate the conclusion that even All right functioning Relationships between science and business they can evolve and require redefinition in response on changing myself needs technological, personnel and market.

Whole analysis leads to the conclusion that cooperation companies Proteon Pharmaceuticals SA with the sector science has a character advanced, flexible and embedded in real life needs companies. This cooperation is example practical Applications agile methods cooperation intersectoral in terms of economy based on knowledge and innovation despite the fact that is not free from systemic barriers.

Based on presented considerations theoretical and a case study by PROTEON PHARMACEUTICALS SA, developed he was left original theoretical model cooperation agile companies with a university higher, presented on Figure 2. This model is attempting synthetic takes dynamic Relationship taking place between sector science and enterprise operating in a demanding and turbulent environment environment biotechnological. At the center of the model, he finds myself agile enterprise. The enterprise is as subject flexible, pro - innovative and adaptable, constantly interacts with the environment knowledge, which is the university higher.

The model assumes that effective cooperation only possible then, when both pages they are in a relationship based on trust, complementarity resources and co-responsibility for the effects projects research and development. University contributes to cooperation potential expert, access to high specialized infrastructure and capacity for education future employees' companies. In turn undertaking introduces this Relationship market recognition needs, possibility testing solutions in conditions practical and ability to quickly commercialization results research. Flow knowledge has a character bidirectional. This means that both both the company and the university they teach myself from myself each other and at the same time They modify own actions in response on appearing myself challenges.

The model illustrates also conditions shore necessary to maintain such cooperation: openness on changes, flexibility organizational, systemic support Financial and common vision long term development. Agility in this take NO it limits myself only to the structure organizational companies, but refers myself also to the way design Relationship intersectoral – short cycles collaborative, iterative approaches to implementation goals research and readiness to introduce corrections on every one stage cooperation.

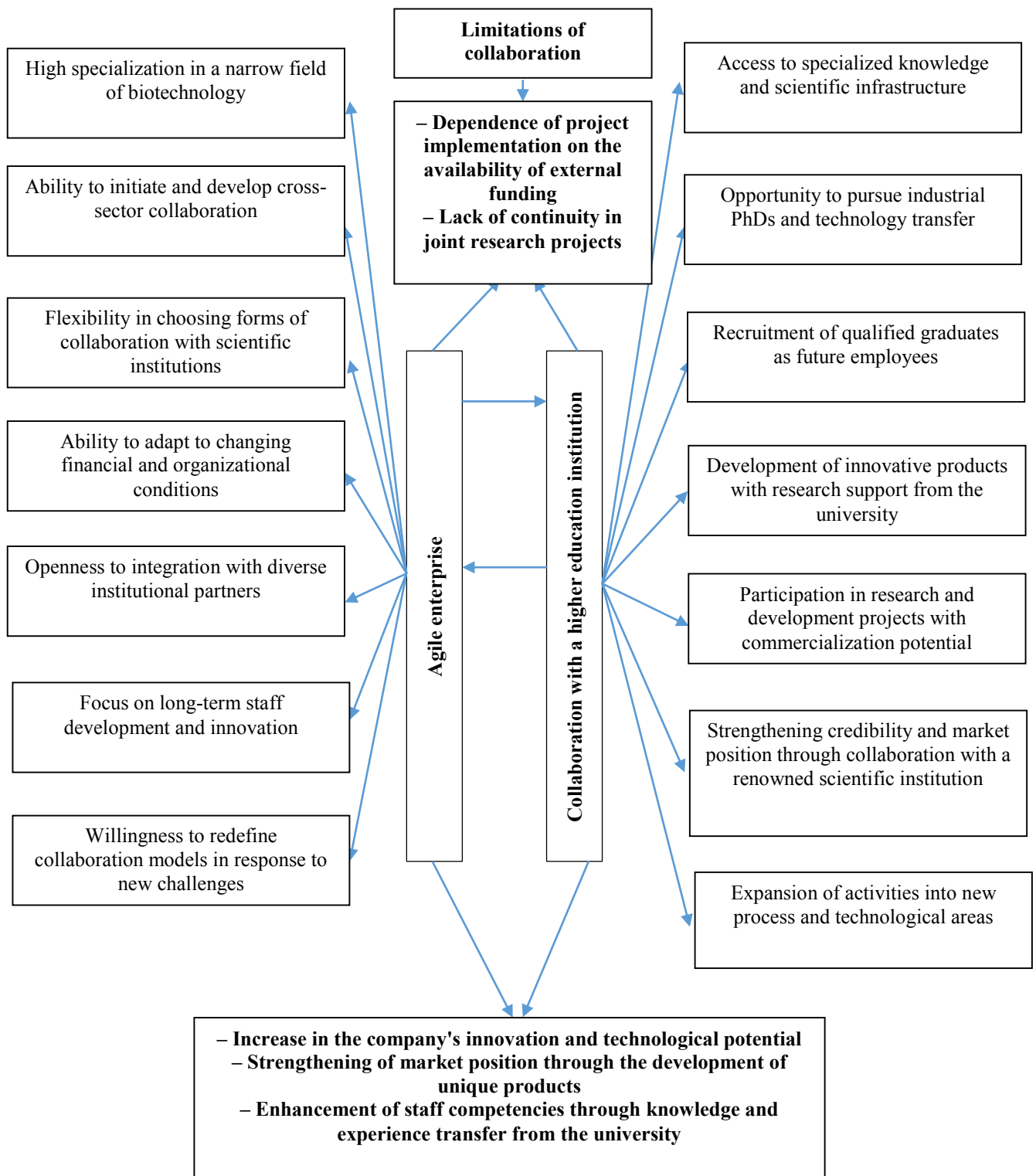


Figure 2. Author's theoretical model cooperation agile companies with a university higher.

Source: Prepared by own.

The value added developed the model is his application potential. It can be practical tool For managers and leaders research, wishing efficiently build relations with universities. And at the same time, I want keep high responsiveness organizational and the pace of

innovation. The model integrates because both elements cognitive (recognition factors success cooperation) and operational (mechanisms implementation cooperation). It gives at the same time possibility diagnosing existing barriers and indications areas for improvement. Thanks ago it supports development companies towards bigger agility and synergy with the sector science (especially in the area of biotechnology constitutes key condition survival and development).

4. Discussion

Presented considerations and results tests qualitative conducted at PROTEON PHARMACEUTICALS SA allow on wording in a row conclusion relating to the conditions effective cooperation between school higher and agile enterprise operating in the sector biotechnology. Collected material empirical indicates that key meaning For Good luck this one cooperation I accept possession appropriate resources infrastructure and competence. However, the most important thing is the organization's openness to sharing knowledge, trust in the partner institutional and flexibility in implementation common solutions. Effective cooperation has to it is clear from specific needs and aspirations both pages and its structure she should to be dynamic. It should because enable adaptation to changing myself conditions market, financial and technological. Specific importance in this in context is gaining mutual replenishment myself resources. University he brings competences research, potential intellectual and access to laboratories, while undertaking provides knowledge about the market, needs users final and possibilities fast commercialization innovation.

In order to cooperate was durable and effective at the same time she should include both common projects research and development, as well as activities of a nature educational and personnel. Example PROTEON PHARMACEUTICALS SA shows that hiring Graduates universities, implementation doctorates implementation and co-creation programs practice student Maybe lead to building integrated ecosystem innovation. In the area this, knowledge academic penetrates with knowledge practical. Such cooperation requires but appropriate support institutional, including access to funds financial, stable mechanisms Coordination and systems grades quality effects common actions.

The culmination carried out the analysis is an original theoretical model cooperation agile companies with a university higher, which I am tidying up dependencies between elements influencing on efficiency this one relationship and indicates That's possible directions further improvement. This model emphasizes necessity leaving from rigid framework of cooperation on thing approaches iterative, adapted to variables conditions surroundings and the supporting myself on relational competences of partners. This approach is included into modern concepts management knowledge, innovation and relationships inter-sectoral. Their effectiveness in the

sector biotechnology you can consider as a condition necessary to achieve permanent development and construction advantages competitive.

Based on carried out considerations theoretical and case study analysis by PROTEON PHARMACEUTICALS SA, formulated They were Recommendations For companies operating in the area biotechnology, which the goal is to build effective and long-term cooperation with universities higher. First of all, to all it's worth it strive to create Relationship based on trust, mutual respect competence and willingness to share myself knowledge and responsibility for the implemented projects. Cooperation with universities she should to be treated as strategic element of the system innovative. It should She to support development new products and technologies and at the same time capital human organization.

It is recommended taking up initiatives of a nature long term. These include common doctorates implementation, commissioning research universities in response on specific challenges technological, co-creation programs practice and active participation in life scientific by conferences, workshops and publications. Enterprises they should to be also Open on cooperation procedural, including activities in the field management, optimization processes technological, analysis Risks Whether implementation ICT tools. In the context growing uncertainty market, it's worth it to develop competences organizational related to agility in management resources, fast taking up decision, iterative implementation solutions and readiness to redefine goals and models cooperation.

It is also important systemic approach to building relations with the environment institutional. It is recommended active engaging in activities regional and national Agency development, network cooperative and consortiums research and industrial. They can be platform for acquisition financing, exchange experiences and initiation common projects. It is also necessary taking action on thing reinforcements competence relational employees, both on the managerial and expert side. They will enable effective moving myself on contact science and business.

To sum up, in the conditions dynamically developing myself market biotechnological, enterprise they should to treat cooperation with universities as durable component strategy organizational. It is an investment in the future and source advantages competitive. Efficiency this one cooperation will be depend both from outlays financial, however first of all to all from quality relationship, clarity goals and abilities both pages to share learning and adaptation to changing myself conditions surroundings.

5. Conclusions

Based on presented case study PROTEON PHARMACEUTICALS SA and analysis results research others authors, you can notice important similarities and differences in terms of cooperation agile companies with institutions scientific. In the study carried out by Calefato et al. (2020) in a large the company programming in Italy, it was emphasized meaning appropriate selection tools communication and management projects in the context practice agile. Implementation tools such as Slack and Jira, along with clear the rules of their use, contributed to improve communication and efficiency teams.

In the context cooperation between the sector biotechnology and institutions scientific it's worth it to relate to the Agile BioFoundry report (2023). It indicates meaning integration resources and competences different partners in order to acceleration processes research and development. This cooperation is based myself on flexible structures organizational. They allow for fast adjustment to the changing myself conditions market and technological.

Comparing these results with experiences PROTEON PHARMACEUTICALS SA, notes it turns out that effective cooperation with universities higher requires both appropriate tools and structures organizational, but also education culture organizational favorable openness, trust and common striving for innovation. In both cases key the ability to adapt and be flexible is important reacting on appearing myself challenges, what is characteristic for approaches agile. Enterprises operating in the sector biotechnological they should invest in development competence agile (both on level both individual and organizational), and actively look partnerships with institutions scientific in order to common creation values and innovations.

In the light changing myself surroundings scientific and economic, future directions research they should concentrate myself on deepened analysis dynamics relations between universities and enterprises biotechnological in the long term on the horizon time. Special meaning Maybe to have identification factors conditioning durability cooperation (including variables social, institutional and technological). It is worth return attention on influence tools digital and systems IT on coordination of activities in models' cooperation agile, taking into account scattered teams design and exchange platforms knowledge.

Important direction research maybe to be also to investigate role universities in shaping competence future employees, taking into account needs agile organizations. Interesting would be too rate effectiveness programs internships, doctorates implementation and joint initiatives didactic. Needed are also tests comparative including different sectors economy based on knowledge. This would allow determining to what extent to a degree mechanisms developed in biotechnology are universal or specific for this sector.

It's worth it to direct attention on aspect culture organizational as factor conditioning willingness to cooperate and mechanisms management relationships intersectoral in terms of uncertainties and limitations financial. Another area demanding exploration is evaluation

influence cooperation with universities on efficiency innovative businesses in perspective quantitative, including through measurement effects commercialization, numbers implemented solutions Whether shortening time developing products.

Tests they can also embrace issue role institutions intermediaries (such as clusters, agencies development regional and consortium, in initiating and maintaining Relationship science - business and mechanisms financing projects common). Finally, an interesting the direction is analysis cooperation transnational, especially in terms of programs European and international, which they create new frames institutional for cooperation between science and industry in terms of global.

In the context of dynamic changes in the scientific and economic environment, further research should focus on the analysis of long-term relations between universities and biotechnology companies. It is particularly important to identify factors influencing the durability of cooperation (including social, institutional and technological variables). It would be interesting to examine the importance of digital tools and IT systems in coordinating activities within agile cooperation models - especially when working in distributed teams. A valuable area of research would also be the assessment of the role of universities in shaping the competences of future employees and the effectiveness of internships, implementation doctorates and joint teaching initiatives. Comparative analyses with other sectors of the knowledge-based economy are also needed. It is also worth conducting research on the impact of organizational culture on willingness to cooperate, as well as assessing the impact of cooperation with universities on the innovativeness of companies and examining the role of intermediary institutions and international cooperation within EU and global programs.

In future research, it is worth focusing on the analysis of long-term effects of cooperation between science and business, primarily in terms of its impact on the commercial results of enterprises and the scientific achievements of universities. It would also be important to examine the durability of partnership relations, their evolution over time, as well as to identify factors that support maintaining cooperation in a changing technological and market environment.

Limitations carried out research they concerned first of all all of their quality the character that based was on single case study, which limits possibility generalizations results on other companies biotechnological. Additionally, the source data was only perspective management one companies, what could affect on subjectivity granted answers. No triangulation methods and limited access to data quantitative made it impossible deepened analysis comparative.

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THE IMPACT OF COMPETITIVE AGGRESSIVENESS ON THE NON-FINANCIAL PERFORMANCE OF THE PRIVATE HEALTHCARE SECTOR

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Purpose: This review aims to synthesize the current understanding of competitive aggressiveness in the private healthcare sector, focusing on its manifestations as a dimension of entrepreneurial orientation and the effects of its application on the non-financial results of companies. It also aims to identify key strategies, conditions, and consequences of competitive aggressiveness in this context.

Design/methodology/approach: A systematic review of the literature published between 2015 and 2025 focusing on relationship between competitive aggressiveness and non-financial performance.

Findings: The review identifies a growing emphasis on competitive aggressiveness in the private healthcare sector, driven by factors such as demographic changes and increasing demands from public sector clients. Private healthcare providers are increasingly adopting strategies aimed at gaining a competitive advantage. The review highlights how competitive aggressiveness manifests in various forms, including aggressive pricing strategies, service differentiation, and strategic alliances, and what impact this has on non-financial results.

Research limitations/implications: The review is limited due to its focus on publications in English and Polish. Limited empirical research specific to private healthcare in Poland requires further investigation.

Practical implications: The findings provide practical guidance for healthcare managers who want to strengthen their competitive position. The review emphasizes the importance of balancing competitive strategies with ethical considerations and patient-centered care.

Originality/value: This review contributes to the literature by providing a focused analysis of the impact of competitive aggressiveness on non-financial outcomes in the under-researched context of private healthcare.

Keywords: Competitive aggressiveness, entrepreneurial orientation, private healthcare sector, competitive strategies, non-financial results.

Category of the paper: Literature review.

1. Introduction

The private healthcare sector, driven by market forces and the pursuit of efficiency, presents a unique environment where competitive aggressiveness can significantly influence the non-financial outcomes of medical facilities (Ijntema et al., 2022). Competitive aggressiveness, characterized by a firm's intensity to outperform rivals, manifests in various strategies within this sector, including service differentiation, technological adoption, and strategic alliances (Glover et al., 2024). Understanding the nuanced impact of such competitive behaviors on non-financial performance indicators, such as patient satisfaction, service quality, and employee well-being, is crucial for healthcare administrators and policymakers (Chang et al., 2017). The escalating competition within the healthcare landscape necessitates a comprehensive examination of how private healthcare providers navigate competitive pressures and their subsequent effects on crucial organizational outcomes that extend beyond mere financial metrics (Susanto, 2019). The existing literature on competitive strategy suggests that aggressive competition can lead to both positive and negative outcomes for firms, with the specific results often depending on the industry context and the resources and capabilities of the organizations involved. In the healthcare sector, the unique characteristics of the services provided, the regulatory environment, and the ethical considerations further complicate the relationship between competitive aggressiveness and organizational performance. Therefore, this study aims to explore the multifaceted impact of competitive aggressiveness on the non-financial performance of private healthcare institutions, shedding light on the strategic choices available to these organizations and the potential consequences for their stakeholders. This study's originality stems from its comprehensive and contemporary synthesis of scientific literature from the last decade, which methodically examines the influence of competitive aggressiveness on the non-financial performance of organizations operating within the previously understudied private healthcare sector. The existing body of literature lacked an encompassing study to gather and analyze evidence regarding the manifestations, determinants, and outcomes of this phenomenon. Prior investigations frequently concentrated on fragmented aspects or failed to account for the latest market and technological developments. By offering systematic knowledge derived from publications between 2015 and 2025, this literature review aims to bridge this gap. Consequently, this article contributes to the advancement of strategic management theory in healthcare and offers pragmatic guidance for healthcare facility administrators.

1.1. Problem Statement

The private healthcare sector operates in an increasingly complex and competitive environment, where the ability to compete effectively is crucial for survival and growth (Naik et al., 2022). In this context, competitive aggressiveness, as a significant dimension of

entrepreneurial orientation, plays a fundamental role in shaping the strategies and financial and non-financial results of private medical entities (Skica et al., 2018). It manifests through various actions, such as pricing strategies, service differentiation, marketing tactics, or expansion initiatives, aimed at gaining and maintaining an advantage in the market (Susanto, 2019).

Despite the growing interest in entrepreneurship in the healthcare sector and the recognition of the importance of competitive aggressiveness, medical facilities are forced to respond to dynamic changes in the market environment (Chang et al., 2017). Factors such as increasing competition, regulatory changes, technological progress, changing demographic needs, and patient expectations constantly modify the landscape in which private healthcare facilities operate. These changes force entities to adapt and often to adopt more aggressive strategies (Elrod, Fortenberry, 2018).

Although individual studies analyze various aspects of competitive aggressiveness, there is a lack of a current, comprehensive synthesis of scientific literature from the last decade that systematically gathers and analyzes evidence regarding the manifestations, determinants, and consequences of competitive aggressiveness and its impact on non-financial business results, particularly in the private healthcare sector. Existing works often focus on fragmented issues or were created before the emergence of the latest market and technological trends (Han et al., 2022). Understanding these dynamic aspects – manifestations, determinants, and consequences of competitive aggressiveness on non-financial results – is crucial not only for managers shaping the strategies of their organizations but also for policymakers responsible for sectoral regulations, as well as for researchers seeking to develop strategic management theory in healthcare (Chang et al., 2017). Given the continuous evolution of the private healthcare sector, a systematic review of the latest empirical and theoretical research is essential to consolidate the current state of knowledge, identify dominant trends, potential research gaps, and formulate recommendations for future analyses. This literature review aims to fill this gap by providing synthesized knowledge on competitive aggressiveness in private healthcare, based on publications from 2015-2025.

2. Methodology

This study employs a systematic review to synthesize the existing literature on competitive aggressiveness in the private healthcare sector, with a particular focus on studies published between 2015 and 2025. The methodological approach aims to provide a comprehensive, unbiased, and reproducible overview of relevant scientific publications. The review involves a systematic search and selection process across several reputable databases, such as PubMed, Scopus, Web of Science, and Google Scholar, using predefined keywords related to competitive aggressiveness, entrepreneurial orientation, non-financial results, and the private healthcare

sector. The search strategy includes a combination of keywords and logical operators to identify articles that directly address or are related to the research problem. Specific search terms include "competitive aggressiveness", "entrepreneurial orientation", "private healthcare sector", "competitive strategies", "market strategies in healthcare", and "non-financial results". The inclusion criteria stipulate that selected articles must be published in English or Polish within the specified timeframe. Exclusion criteria encompass publications lacking empirical evidence or theoretical foundations. Initial search results are screened based on titles and abstracts to remove irrelevant articles, followed by a full-text assessment of the remaining articles to determine their eligibility for inclusion. Out of 154 initially identified articles, a rigorous screening process led to the exclusion of 99 based on title and abstract, resulting in a final selection of 55 articles for in-depth analysis. The collected data is synthesized using thematic analysis to identify recurring themes, patterns, and gaps in the literature, providing a comprehensive overview of the current state of knowledge on competitive aggressiveness in the private healthcare sector.

3. Results

The impact of intense competitive actions on the non-financial results of medical facilities is significant. The limited nature of public healthcare entities has led to the dynamic development of the private healthcare sector, especially in the area of new private medical businesses (Skica et al., 2018). As the landscape of the private healthcare sector continues to evolve, a systematic review of empirical research in the field of entrepreneurial orientation is crucial for developing current insights (Zhang et al., 2023). The effects of aggressive competition on companies can be both positive and negative. The growing number of private entities in the healthcare sector leads to fierce competition, forcing organizations to adopt aggressive strategies for survival and development (Głód, 2016). The intensity of competition affects healthcare services, with more and more players vying for market share and patients. The growth of for-profit healthcare organizations influences the strategies used to attract patients, which can affect the quality of services and costs (Han et al., 2022). Aggressive competition in the private healthcare sector can lead to innovation and improved service quality, as organizations strive to differentiate themselves and attract patients (Garattini, Padula, 2018).

Competitive aggressiveness, as an aspect of entrepreneurial orientation, manifests in the healthcare sector through various strategic actions, including pricing strategies, service differentiation, marketing tactics, and expansion initiatives (Chang et al., 2017). Types of Aggressive Competitive Practices in the Private Healthcare Sector and Their Manifestations are presented in Table 1. The private healthcare sector, characterized by a market environment where commercial entities coexist with public entities, creates a unique and unparalleled

environment for competitive behaviors (Indounas, Arvaniti, 2015). In this sector, entities constantly strive to attract patients, secure contracts, and maintain a competitive advantage through various competitive maneuvers (Purcărea, 2016). Risk-taking, proactivity, and innovation are fundamental elements of entrepreneurial orientation that influence how organizations manage opportunities and threats in their markets (Gaweł, 2023).

Table 1.

Types of Aggressive Competitive Practices in the Private Healthcare Sector and Their Manifestations

Type of Competitive Action	Manifestation in Healthcare	Key Aspects/Examples
Pricing Strategies	Setting prices to attract patients and gain market share.	Offering discounts, service packages, setting competitive prices, dynamic pricing, value-based pricing.
Service Differentiation	Highlighting the company's offer through unique, specialized, or innovative services.	Investing in advanced medical technologies, developing new services that respond to market needs, implementing telemedicine and artificial intelligence.
Marketing Tactics	Using various marketing channels to increase visibility, promote services, and build a strong brand identity.	Advertising, public relations, internet marketing, interpersonal communication, building a strong brand based on trust and loyalty.
Technology Adoption and Innovation	Implementation of new technologies to improve service delivery, patient experience, and gain competitive advantage.	Digital transformation, mobile applications, health monitoring devices, data analysis, investments in research and development of new treatment methods and diagnostic tools.
Market Expansion Initiatives	Expanding market presence through organic growth or acquisitions.	Mergers, acquisitions, creation of new branches, strategic alliances, and partnerships to expand service offerings and market share.
The Impact of Regulation and Health Policy	Adapting strategies to changing regulations and health policies in order to take advantage of new opportunities and minimize risks.	Adapting to regulatory changes, taking advantage of new opportunities arising from health policy.

Source: own study.

The healthcare sector is facing challenges related to evolving demographic needs and rising customer expectations, leading to the search for effective business models and strategic approaches (Hussain et al., 2024). Competitive aggressiveness in the private healthcare sector is driven by several factors, including increased competition, regulatory changes, and technological advancements. In addition, autonomous units in the healthcare sector, which have the freedom to make independent decisions, tend to achieve better results, potentially leading to more aggressive competitive strategies (Brandt, Znotka, 2019). Competitiveness is shaped by the degree to which companies interact with each other and compete to maintain or improve their market position. These factors force private entities to adopt aggressive strategies to maintain a high level of competitiveness and development in the market (Ibikunle et al., 2023).

The impact of labor costs on the form of employment is also significant in the context of competitive aggressiveness. Companies may be inclined to use aggressive competitive strategies to offset higher labor costs or to exploit a cost advantage. In addition, socio-economic changes in society have become a driving force behind the growing demand for healthcare services (Capuno et al., 2019).

Healthcare organizations compete to maintain or improve their market position, and their strategic decisions regarding healthcare are based on statistical data. (Kelly, Young, 2017) Healthcare organizations must ensure patient satisfaction to remain competitive. Several studies suggest that private healthcare providers often compete based on service quality and patient experience (Setyawan et al., 2020). Competitive entities focus on minimizing costs and maximizing profits while improving service quality, ensuring patient satisfaction, and achieving positive health outcomes (Bertke, Nufer, 2021). Improving operational efficiency can result from competition, leading to better resource allocation, streamlined processes, and reduced costs (Yinusa, Faezipour, 2023). However, excessive competitive aggressiveness can negatively impact an organization's financial results, suggesting the need to find a balance between competitiveness and financial stability (Głód, 2016).

Among the studies, certain themes dominate, relating to various competitive strategies employed by private entities in the healthcare sector. These include pricing strategies, such as offering discounts or bundled services to attract patients, and service differentiation strategies, such as investing in advanced medical technologies (Trinh, 2020).

Many researchers focus on the impact of prices on competitiveness, examining how private entities use pricing models to attract patients and gain market share. These strategies may include competitive pricing, where prices are set to match or be lower than competitors' prices, and dynamic pricing, which adjusts prices based on demand and other market factors (Neussner et al., 2021). Some providers may apply value-based pricing, emphasizing the quality and outcomes of care in their pricing models. Others may focus on offering price packages for specific services or care packages to increase market share (Bates et al., 2017).

Providing unique or specialized services is a key strategy discussed in several studies, emphasizing the importance of innovation and quality in attracting patients and maintaining a competitive advantage. The development of new services is a key mechanism for healthcare organizations to respond to market needs and improve their competitive position (Andersson et al., 2023). Organizations achieve value creation for the customer through market orientation and effective knowledge development. The integration of new technologies, such as telemedicine and artificial intelligence, has also been investigated to improve service delivery, patient experience, and competitive advantage (Ludwiczak, 2016).

Marketing medical services is a strategy that involves the use of various marketing channels to increase visibility, promote services, and build a strong brand identity. Private healthcare providers can invest heavily in advertising, public relations, and internet marketing to reach potential patients (Ekiyor, Altan, 2020). Aggressive marketing activities, including advertising

and branding, are commonly discussed as tools used by private entities to increase their visibility and attract patients (Elrod, Fortenberry, 2020). Some institutions distinguish themselves through communication based on solid positioning, tailoring their messages to specific patient groups (Purcărea, 2016). Digital marketing, including social media and search engine optimization, is becoming increasingly important for acquiring new patients and maintaining their engagement. Interpersonal communication can improve customer satisfaction and increase the perceived value of medical services (Chichirez, Purcărea, 2018).

Recent trends also highlight the growing importance of digital transformation in achieving and maintaining a competitive advantage (Herrmann et al., 2018). The implementation of digital technologies in healthcare, such as mobile applications and personal health monitoring devices, improves patient engagement, provides convenience, and gives access to real-time health data. By utilizing data analysis, providers can gain practical information about patient behavior and market trends to improve decision-making and refine their strategies (Amft, 2018). Research often mentions the role of technology in driving competitive behavior. The rapid development of medical technologies can provide a competitive advantage to those who implement them quickly and effectively. Private healthcare providers must constantly invest in new technologies to remain competitive (Mamyrbekova et al., 2020). This promotes innovation in service delivery, technology implementation, and patient care models. Medical facilities are investing in research and development to create new and improved treatments, diagnostic tools, and healthcare solutions (Nusem, 2018).

Some studies discuss how private healthcare entities expand their market presence through mergers, acquisitions, and the establishment of new facilities. This can lead to reduced overall costs, a broader range of services, and increased market power. Strategic alliances and partnerships are also used to expand service offerings and market share (Staňková et al., 2020).

Many studies also analyze the impact of health policies and regulations on competitive opportunities. Changes in health care policies and regulations have a significant impact on competitive behavior, and private entities are adapting their strategies to comply with regulations and exploit new opportunities (Varkevisser, 2019). The regulatory environment influences the dynamics of competition. Understanding it is essential for providers to effectively navigate the market and respond to changes (Fr, Santilli, 2019). Changes in health care regulations can create both opportunities and challenges for private providers, affecting their ability to compete and innovate (Ellis et al., 2024).

However, the consequences of competitive aggressiveness are not always positive, and several studies indicate potential drawbacks such as cost escalation. Aggressive marketing strategies and the introduction of too many new services simultaneously can lead to an increase in healthcare costs, potentially limiting accessibility for some patients (Han et al., 2022). Private entities may focus on attracting healthier, wealthier patients due to lower treatment costs and higher profits, neglecting those with complex or costly medical needs, which deepens inequalities in access to medical services (Werbeck et al., 2021).

4. Discussion

This section analyzes the collected information in the context of recommendations for the private healthcare sector. This distinguishes it from other industries. The emphasis is on identifying patterns, trends, and consequences of aggressive competitive behaviors.

Aggressive competition significantly shapes the private healthcare market, influencing both service offerings and patient access. While fostering innovation and potentially improving service quality, such competition can also lead to cost escalation and unequal access to care (Barros et al., 2015). Market dynamics are further complicated by the strategic choices of private entities, including mergers, targeted marketing, and the adoption of new technologies, all of which affect the overall competitive landscape and, ultimately, patient outcomes (Geyman, 2021).

Competitive aggressiveness in the private healthcare sector leads to a dynamic and evolving market environment. Entities must constantly adapt their strategies to remain competitive, leading to continuous innovation and improvements in service delivery (Szromek, 2018).

Aggressive competitive strategies often require private entities to prioritize patient satisfaction and treatment outcomes. This can lead to more personalized and patient-centered care models. (Marzorati, Pravettoni, 2017) Aggressive competition can also create ethical dilemmas for private healthcare entities. For example, there may be incentives to prioritize privately insured patients over publicly insured patients, leading to inequalities in access to care (Askarzade et al., 2024).

Competitive aggressiveness in the private healthcare sector can have a complex impact on patient satisfaction. On the one hand, intense competition between facilities can lead to higher service standards, the implementation of innovative solutions, and personalization of care, which directly translates into higher patient satisfaction (Setyawan et al., 2020). Competing entities often invest in improving patient comfort, reducing waiting times for visits, and expanding the range of services to attract and retain patients (Bertke, Nufer, 2021). On the other hand, excessive competitive aggression, focused solely on profit, can lead to compromises in the quality of services provided, increased costs, and unequal access to care, which negatively affects the patient experience and their level of satisfaction (Barros et al., 2015).

Competitive aggressiveness in the private healthcare sector significantly impacts treatment outcomes. On the one hand, it stimulates the implementation of innovative technologies and treatment methods, which can lead to improved therapeutic efficacy and faster patient recovery (Jayadevappa et al., 2023). On the other hand, excessive competitive pressure can lead to a focus on procedures that generate high profits, at the expense of treating more complex and costly cases, which may reduce overall treatment outcomes and exacerbate inequalities in access to care (Barros et al., 2015).

Competitive aggressiveness in the private healthcare sector has a complex impact on the operational and process efficiency of medical facilities. On the one hand, intense competition can stimulate process optimization, the implementation of modern technologies, and resource management streamlining, leading to increased efficiency (Wang et al., 2023). On the other hand, excessive emphasis on profit can lead to cost-cutting, which negatively affects the quality of medical services provided and may lead to a reduction in operational efficiency in the long term (Imani et al., 2022).

Competitive aggressiveness in the private healthcare sector can significantly affect sustainability and social responsibility. On the one hand, competitive pressure may encourage facilities to optimize processes and implement innovations, which can lead to more efficient use of resources and a reduction in negative environmental impact (Bertke, Nufer, 2021). On the other hand, excessive emphasis on profit can lead to the neglect of social aspects, such as the accessibility of services for all social groups, ethical business practices, and investments in local communities. Facilities may be more inclined to cut costs at the expense of the quality of services provided or to avoid treating patients with complex needs, which undermines the principles of social responsibility (Puttkammer et al., 2023). The revealed relationships between competitive aggressiveness and non-financial performance of companies are shown in Table 2.

Table 2.

The Impact of Competitive Aggressiveness on Selected Non-Financial Outcomes of Medical Facilities in the Private Sector

Non-Financial Outcome	Potential Positive Impact of Aggressive Competition	Potential Negative Impact of Aggressive Competition
Quality of Medical Services	Raising service standards, striving for excellence to attract patients.	Potential compromises in quality with an excessive focus on profit, cost-cutting at the expense of quality.
Patient Satisfaction	Higher service standards, personalized care, reduction in waiting times, expansion of service range.	Negative patient experiences resulting from quality compromises, increased costs, or unequal access.
Treatment Outcomes	Stimulation of the implementation of innovative technologies and treatment methods, which can improve therapeutic efficacy.	Focus on procedures generating high profits at the expense of treating more complex and costly cases, which may lower overall treatment outcomes.
Operational and Process Efficiency	Optimization of processes, implementation of modern technologies, streamlining of resource management.	Cost-cutting negatively affecting the quality of medical services and long-term operational efficiency.
Innovation	Stimulation of innovation in service delivery, technology implementation, and patient care models.	Focus on quick, easily implementable profit-generating innovations, instead of long-term, more complex research.
Service Accessibility and Equity in Access to Care	Potentially broader range of services and greater choice for patients.	Concentration on healthier, wealthier patients, neglecting those with complex or costly medical needs, deepening inequalities. Cost escalation limiting accessibility for some patients.
Ethical Issues	Increased awareness of the need to build trust and transparency.	Conflicts of interest, inappropriate marketing tactics, potential endangerment of patient safety, prioritization of privately insured patients.

Cont. table 2.

Sustainability and Social Responsibility	Process optimization and innovation implementation can lead to more efficient resource use and reduction of negative environmental impact.	Neglect of social aspects like accessibility for all groups, ethical practices, investments in local communities in favor of profit maximization.

Source: own study.

Competitive aggressiveness in the private healthcare sector has a complex impact on patient satisfaction. For example, a study by Smith et al. found that hospitals in highly competitive markets were more likely to invest in patient amenities and services, leading to higher patient satisfaction scores. On the other hand, Brown reported that in some cases, the pursuit of higher profits led to shorter consultation times and reduced staff attention, negatively impacting patient satisfaction. Competitive aggressiveness in the private healthcare sector significantly impacts treatment outcomes. A study by Jones et al. showed that facilities in competitive markets were quicker to adopt new technologies and treatment methods, leading to improved outcomes for certain conditions. However, a report by Davis indicated that some facilities focused on high-profit procedures at the expense of more complex cases, potentially reducing overall treatment outcomes and exacerbating inequalities in access to care. Competitive aggressiveness in the private healthcare sector has a complex impact on the operational and process efficiency of medical facilities. For example, a study by Garcia found that intense competition led to process optimization and the implementation of modern technologies, increasing efficiency. However, a review by Wilson noted that excessive emphasis on profit could lead to cost-cutting measures that negatively affect the quality of medical services and reduce operational efficiency in the long term. Competitive aggressiveness in the private healthcare sector can significantly affect sustainability and social responsibility. Smith found that competitive pressure encouraged facilities to optimize processes and reduce their environmental impact. However, a report by Anderson indicated that excessive emphasis on profit could lead to the neglect of social aspects, such as accessibility of services for all social groups and ethical business practices.

To visually represent the central argument of this analysis, a conceptual model was constructed (Figure 1). This model illustrates the complex interrelation between the observed manifestations of competitive aggressiveness within private healthcare facilities and the corresponding non-financial outcomes they realize. The model underscores the significant role of moderating factors, which collectively determine the ultimate character and intensity of the noted influence.

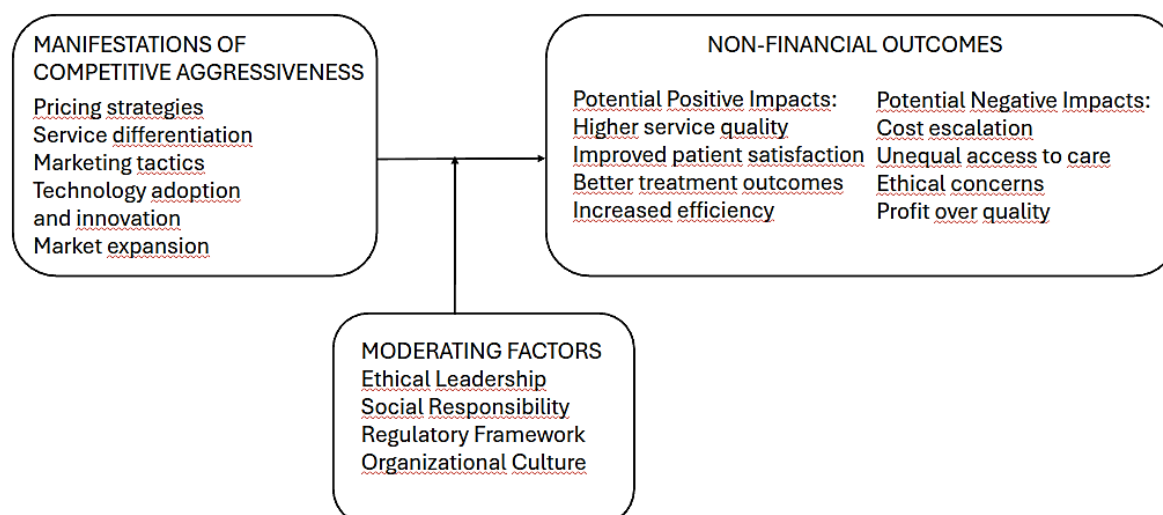


Figure 1. Relation between the observed manifestations of competitive aggressiveness and the corresponding non-financial outcomes.

Source: Own study

The main axis of the model shows how specific manifestations of aggressiveness, such as service differentiation or technology adoption, lead to twofold results: on the one hand, they can increase the quality and satisfaction of patients, and on the other hand, lead to cost escalation and ethical problems. A key role in this process is played by moderating factors, such as ethical leadership or organizational culture. They are not a direct cause of the results, but they determine the strength and direction of the main relationship. They answer the question of in what conditions competitive aggressiveness brings more benefits and in what losses. The model therefore proves that the relationship between strategy and its effects is strongly dependent on the organizational and ethical context in which the facility operates.

Based on the obtained data, several recommendations can be developed for both medical facilities and policy makers and market regulators. To sustain a competitive edge, consistent investment in novel medical technologies, digital advancements, and robust research and development initiatives is advisable, positioning innovation as a fundamental strategic imperative. Instead of primarily competing on cost, emphasis should be placed on distinguishing offerings through distinctive, specialized services that ensure superior quality and an enhanced patient experience. Furthermore, fostering a culture that champions innovation, empowering employees to contribute to inventive solutions and participate in strategic decision-making, is essential. Allocating resources for staff training and continuous development is paramount in upholding service excellence and cultivating patient confidence. Ethical leadership, marked by demonstrable integrity and transparency, is crucial for setting a benchmark of conduct for the entire organization. Moreover, advancements in operational and process efficiency can be achieved through dedicated efforts toward process optimization, strategic resource allocation, and diligent cost reduction initiatives. It is crucial to strive to maintain a balance between competitive aggressiveness and these actions at all costs, as overly

intense competitive actions can paradoxically reduce the quality of services and lead to a deterioration of the facility's performance.

Health policy should proactively counteract adverse trends such as escalating costs, increasing disparities in access to care, and unethical marketing tactics. Regulatory frameworks should be established to incentivize entities to compete on service quality, treatment efficacy, and patient satisfaction, rather than solely on price. Regulations should foster the adoption of innovations that offer tangible benefits to patients and the healthcare system, beyond immediate profitability. Furthermore, the development and implementation of more precise metrics are necessary to evaluate the intensity of competition and its effects on critical aspects of the healthcare system, including service quality, efficiency, and accessibility. Decision-makers should analyze and implement models that harness market dynamics to enhance efficiency, while simultaneously ensuring the achievement of public health objectives, such as equitable access to care.

4.1. Future Research Directions

Future research should explore how different organizational structures and governance models within private healthcare affect their competitive behavior and non-financial performance. Investigation into the influence of specific leadership styles on the adoption of aggressive competitive strategies, as well as their subsequent impact on organizational culture and ethical standards is needed (Glover et al., 2024). Longitudinal studies could track the long-term effects of aggressive competition on patient outcomes, access to care, and the financial stability of healthcare organizations. It is essential to develop more refined metrics for measuring competitive intensity and its impact on various aspects of healthcare performance, including quality, efficiency, and patient satisfaction. Future studies could also explore the role of regulation and policy in shaping competitive dynamics and mitigating potential negative consequences of aggressive competition in the private healthcare sector. Exploration of the effects of inter-organizational relationships on competition and collaboration is also needed (Westra et al., 2016). Future research should aim to develop a more nuanced understanding of the relationship between competitive aggressiveness and non-financial performance in the private healthcare sector, taking into account the moderating effects of various organizational and environmental factors (Urban, Maboko, 2020). To promote sustainable healthcare practices, organizations should collaborate with stakeholders and invest in technology (Hussain et al., 2024). It is imperative that leaders demonstrate ethical behavior, ensuring honesty and fairness in their interactions, which sets a positive example for their teams (Şahne, Şar, 2017). Furthermore, managers and executives in the healthcare industry require training to prioritize sustainable innovations in health economics, social policy, and management (Hussain et al., 2024). Such actions are necessary for the successful adoption of sustainable technologies (Hussain et al., 2024). This involves the use of modern healthcare institutions' competitiveness management principles (Safonov et al., 2022).

The changing healthcare landscape is becoming more entrepreneurial, attracting talent from diverse industries to address complex challenges (Urban, Maboko, 2020). Effective leaders in healthcare must exhibit flexibility and patient-centeredness to navigate the dynamic healthcare system, implementing changes for improved healthcare delivery and health outcomes (Sayyed et al., 2024). As the healthcare industry undergoes rapid changes, leaders and managers should foster higher levels of entrepreneurship in their healthcare organizations (Urban, Maboko, 2020). This entrepreneurial drive can enable healthcare organizations to identify opportunities, develop innovative solutions, and adapt to evolving patient needs (Glover et al., 2024; Ratten, 2015).

For managers operating in the competitive environment of private healthcare, finding a balance between competitive aggressiveness and social responsibility is crucial. This requires developing strategies that not only allow for achieving a market advantage but also ensure high-quality services, equal access to care, and ethical business practices (Grazier, 2015). It is also essential to promote a culture of innovation and continuous improvement, where employees are encouraged to seek new solutions and improve existing processes, which can contribute to both increased efficiency and improved patient satisfaction (Ferraz et al., 2021).

In addition, it is crucial to invest in the training and development of employees to ensure the high quality of services provided and build patient trust. Healthcare organizations can nurture an innovative culture by valuing innovation and empowering employees to explore new approaches (Andersson et al., 2023). Leaders can encourage innovation by involving staff in decision-making, providing resources for experimentation, and celebrating both successes and failures as learning opportunities (Gürkan, Tükeltürk, 2016). Ultimately, the long-term success of private healthcare facilities depends on their ability to reconcile competitive aggressiveness with ethical principles and social responsibility, which will allow them to build a strong market position while maintaining patient trust and contributing to the overall well-being of society. The key to success in the healthcare industry lies in making innovation and aggressive competition a strategic priority (Bates et al., 2017).

5. Conclusion

This study examines how competitive strategies affect non-financial results in private medical facilities. The rise of private healthcare intensifies competition, prompting organizations to adopt aggressive approaches to maintain market share. This dynamic is further fueled by patient expectations, demographic shifts, technological progress, and regulatory changes (Brown, 2016).

Competitive aggressiveness in the private healthcare sector manifests through strategic actions like pricing strategies, service differentiation, technology investments, innovative service offerings, intensive marketing, and market expansion (Trinh, 2020).

The effects of competitive aggressiveness on non-financial results are intricate. While intense competition may encourage innovation in service delivery, technology, and care models, leading to improved quality, patient satisfaction, and operational efficiency, it also presents potential drawbacks.

However, too much competition can create inequalities in who gets care, as some facilities might focus on the most profitable patients, leaving others behind. Plus, there are ethical issues with certain marketing tactics and potential conflicts of interest. Cutting costs too aggressively to make money can also mess with the quality of care.

The article emphasizes that aggressive competition has a complex impact on patient satisfaction. It affects treatment outcomes, which it can improve through innovation, but also worsen through patient selection, then operational efficiency, which it can increase, but also decrease in the long run through excessive savings, and sustainable development and social responsibility, which it can stimulate as ecological efficiency, but also lead to the neglect of social aspects.

The analysis indicates the need for managers to find a balance between competitive aggressiveness and financial stability, social responsibility, and ethics. Investing in innovation, technology, staff development, and building a strong patient-oriented brand becomes key. The role of leadership in promoting a culture of innovation and ethical conduct is highlighted.

The article concludes with the indication of future research directions, which should include, among other things, the impact of organizational structures and management models on competitive behavior, the role of leadership styles, the long-term effects of competitive aggressiveness, and the development of better metrics for its measurement and impact on various aspects of healthcare.

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THE ROLE OF THE TRANSPORT SECTOR IN THE POLISH ECONOMY: AN INPUT–OUTPUT APPROACH

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Purpose: The aim of this article is to evaluate the role of the transport sector within the structure of the Polish economy between 2010 and 2020 using input–output analysis tools, with particular emphasis on the exogenous approach.

Design/methodology/approach: The study employs Leontief and Ghosh models to calculate traditional multipliers (output, value added, income) and conducts a simulation of demand shocks based on the exogenous approach. The analysis is based on input–output tables from Statistics Poland for the years 2010, 2015, and 2020.

Findings: The results indicate strong interdependencies between the transport sector and other branches of the national economy, highlighting its dual role as both a supplier and a recipient of intermediate services. The land transport subsector exhibits the highest level of sectoral integration and generates substantial multiplier effects.

Research limitations/implications: The study does not account for employment effects due to the unavailability of satellite data. Future research should consider the use of dynamic models and the integration of environmental and social data.

Practical implications: The results may support investment decisions and transport policy by identifying the sectors most responsive to transport-induced economic stimuli.

Social implications: The analysis highlights the systemic importance of transport as a factor fostering regional development, social cohesion, and national economic competitiveness.

Originality/value: This article contributes new value by applying an exogenous modelling approach to assess the structural role of transport, a perspective rarely explored in the Polish literature.

Keywords: transport, input–output model, economic multipliers, Polish economy, intersectoral analysis.

Category of the paper: Research paper.

1. Introduction

The transport sector plays a vital role in modern economies. There is a strong correlation between the development of the transport system and the overall growth of the national economy. Efficient and well-developed transport serves both as a prerequisite for and a driver

of economic growth (Rydzkowski, Wojewódzka-Król, 2000). The literature emphasises its dual role, on the one hand, as a provider of services essential for the smooth functioning of other sectors, and on the other, as a recipient of investment resources, both public and private (Koźlak, 2007).

Transport facilitates the exchange of goods and services by enabling the movement of raw materials, semi-finished products, and final goods, serving both productive and non-productive sectors, such as education and healthcare. It provides communication services to the population, influences the location of production and settlement, and supports administrative cohesion as well as the country's defence functions (Rydzkowski, Wojewódzka-Król, 2000; Koźlak, 2007). It may be stated that transport accompanies virtually all economic and social activities, constituting an indispensable element of development, acting as the "circulatory system" of the national economy (Mindur, 2007). On the other hand, the functioning of the transport system itself depends on supplies of fuel, energy, rolling stock, machinery, infrastructure, and human labour, which underlines the reciprocal interdependence between transport and other sectors of the economy (Rydzkowski, Wojewódzka-Król, 2000; Koźlak, 2007).

The significance of transport is reflected in a range of economic indicators that allow for the assessment of its impact on economic growth and the level of socio-economic development. The most commonly used measures include the value of turnover in the transport sector, the sector's contribution to gross domestic product (GDP), employment levels in the industry, the value of investment outlays, and transport intensity indicators (Butyter, 2015; Fajczak-Kowalska, Kowalska, 2018; Koźlak, 2018; Handayani et al., 2020; Vukić, Mikulić, Keček, 2021).

According to data from Statistics Poland, between 2010 and 2023, revenues from service sales in transport entities increased from PLN 124.9 million to PLN 454.5 billion, while average employment increased from 478.8 thousand to 724.1 thousand persons (GUS, 2011, 2024b). However, these figures refer to entities classified under Section H, "Transportation and Storage", excluding the division "Postal and Courier Activities". Therefore, they encompass more than just transport companies. The share of Section H in GDP increased from 4.77% in 2010 to 6.09% in 2023. Meanwhile, the share of investment outlays for Section H in total investment expenditures was 19.65% and 19.39%, respectively. These indicators confirm the crucial role and growing importance of the transport and storage sector in the Polish national economy.

At the same time, between 2010 and 2023, a noticeable decrease in transport intensity was observed. This indicator reflects the ratio of transport inputs (e.g., freight volumes in tonnes, tonne kilometres, or the value of transport output) to the value of outputs achieved in other sectors of the economy (e.g., GDP). In 2010, these indicators amounted to 1,241 tonnes per million PLN of GDP, 213 tonne-kilometres per thousand PLN of GDP, and PLN 125 per thousand PLN of GDP, respectively, while in 2023, the corresponding figures were 655 tonnes, 145 tonne-kilometres and PLN 105. The evident decline in transport intensity indicates

a reduced share of transport costs in total production expenditures. This may result from increasing efficiency in the use of transport resources, modernisation of the transport network, or structural changes in the economy.

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However, indicators based on current-price GDP may be unreliable, as inflation distorts their value, thereby limiting their usefulness as a measure of actual transport intensity (Rydzkowski, Wojewódzka-Król, 2000). Furthermore, while the indicators presented are useful, they are of an aggregate nature and do not allow the identification of indirect and induced effects generated by the transport sector in relation to other branches of the economy. Consequently, there is a growing tendency to employ more detailed analytical tools, such as input–output models. This approach enables the identification of intersectoral linkages and the analysis of multiplier effects resulting from transport activity—effects that cannot be captured by conventional descriptive indicators.

Despite numerous studies on the transport sector in Poland, there remains a lack of analysis based on input–output models that comprehensively capture its direct, indirect and induced effects on the economy. This article seeks to address this gap by applying an extended input–output approach, which includes both traditional multipliers and linkage analysis (backward/forward linkages), as well as exogenous simulations of economic impulses generated by the transport sector. The purpose of the study is to assess the importance of transport within the structure of the Polish economy in the years 2010–2020 by identifying its intersectoral links and its impact on other sectors using both classical and exogenous perspectives.

The remainder of the article is structured into four main sections: Section Two presents a literature review on the application of input–output models in transport sector analysis; Section Three discusses the research methodology and data sources; Section Four provides the analytical results and their interpretation; and Section Five contains conclusions and recommendations.

2. Literature Review

Input–output (I–O) models are among the fundamental tools used in economic analysis and are widely applied in studies of the transport sector. They allow the identification of intersectoral linkages and the assessment of multiplier effects, making them useful in both academic research and the practice of public policy formulation (Yu, 2018). As Chrzanowski (2014) notes, given the current availability of statistical data, input–output models have become an almost indispensable tool for examining the structure of market economies.

In addition to classical input–output (I–O) models, their extensions are increasingly applied in the literature, offering a more complex representation of economic phenomena. Among the most commonly used are multi-regional input–output (MRIO) models, which allow for the analysis of the spatial effects of infrastructure investments (Marzano, Papola, 2008), and computable general equilibrium (CGE) models, which account for interactions between supply and demand across different markets as well as price variability, making them particularly useful for analysing dynamic macroeconomic processes (Njoya, Ragab, 2022; Rosik, Wójcik, 2023). The choice of a specific model depends on the research objective – classical I–O models are well-suited for multiplier and structural analyses, whereas the CGE approach enables scenario-based simulations that incorporate market mechanisms.

The application of input–output models in transport sector research can be grouped into three main analytical strands, each reflecting different research objectives and perspectives. First, there are studies focusing on multiplier effects and the influence of the transport sector on other parts of the economy. Second, research employing the exogenous approach, in which transport acts as a source of macroeconomic impulses. Third, studies that examine the structural position of transport within the intersectoral system. This classification structures the remainder of the literature review, facilitating the identification of dominant trends and research gaps.

One of the most common applications of I–O models in transport studies is the analysis of multiplier effects, including the impact of the sector on production, value added, and employment in the economy. For example, Lim et al. (2015) examined the effects of road and rail transport on the South Korean economy in the years 2003–2009, showing that despite its relatively low value added, road transport plays a key role as a channel for transmitting economic impulses. Alises and Vassallo (2016) focused on comparing the demand for road freight transport in Spain and the United Kingdom, analysing the relationship between economic structure and the demand for transport services. Using input–output tables, the authors measured the volume of transport associated with domestic production and consumption, emphasising the importance of detailed sectoral modelling in transport analysis. In the Polish context, a notable example of this approach is the study by Lach et al. (2022), who estimated the potential effects of implementing Hyperloop technology, pointing to broad multiplier effects in both industry and the labour market.

There is a growing interest in the literature in the exogenous approach, where the transport sector is not analysed as a passive recipient of final demand but as an active source of impulses stimulating the economy. For example, Lee and Yoo (2016) treated four transport modes, rail, road, water, and air, as exogenous factors and analysed their impact on other sectors of the South Korean economy. Muryani and Swastika (2018) adopted a similar methodology in their study of the Indonesian economy, applying a supply-side approach in which primary inputs were treated as drivers of economic growth. The exogenous model was also used by Vukić et al. (2021) in analysing the Croatian economy, and Daldoul and Dakhlaoui (2025) considered it more accurately reflects the role of transport in developing countries. In Poland, the exogenous model was applied by Białek and Tyc (2025), who studied the impact of public support policies for the land transport sector during and after the COVID-19 pandemic. Their analysis, which combined macroeconomic and microeconomic perspectives, allowed for an assessment of the competitiveness relative to its suppliers and business partners.

The third strand of research focuses on analysing the position of transport within the economic structure, with particular emphasis on its intermediary functions and role in the network of intersectoral linkages. This type of study allows for the assessment of the strategic importance of the transport sector in production, service, and investment flows. For example, Wang and Yan (2023), analyzing the logistics sector in China, emphasised its multidimensional nature, which includes not only transport operations, but also infrastructure, information management, and digital components. In the Polish context, Fura (2017), using data from Statistics Poland, identified transport as one of the key sectors of the national economy. Similarly, Huderek-Glapska et al. (2016) highlighted the importance of regional airports as critical nodes in economic linkages, analysing both operational and investment-related effects of air transport. Such studies point to the central role of the transport sector in the system of economic flows and its potential as a generator of indirect effects.

Input–output models are used in transport analyses in various economic and geographic contexts—including both highly developed countries such as South Korea (Lee, Yoo, 2016), Germany (Koesler, 2013) and Croatia (Vukić, Mikulić, Keček, 2021), and developing economies such as China (Zhao, Ding, 2024), Tunisia (Daldoul, Dakhlaoui, 2025), Indonesia (Muryani, Swastika, 2018), and Nigeria (Ojaleye, Narayanan, 2022). The spatial scope of the analyses includes both national and regional levels. Examples of regionally focused studies include research on interregional trade flows in Poland (Rokicki, Vázquez, Goliszek, 2024) and the impact of regional airports (Huderek-Glapska, Inchausti-Sintes, Njoya, 2016). Furthermore, the study by Handayani et al. (2020) indicates that the transport sector can serve as a foundational sector that effectively stimulates economic growth. Cross-country and multiscalar comparisons help to better understand the conditions under which transport influences the structure of the economy, including variations due to development levels, industrial structure, and spatial policy.

The literature review demonstrates a growing interest in the application of input–output models in transport research, encompassing various methodological approaches (classical and exogenous), different levels of analysis (national and regional), and a wide range of applications—from multiplier effect assessments to structural investigations. Despite this diversity, relatively few studies integrate an analysis of the structural role of the transport sector with an exogenous modelling of economic impulses. In the context of Poland, although input–output models have been applied to study the transport sector, there is a noticeable lack of research adopting an exogenous perspective, where transport is treated as a source of economic stimulus. This study seeks to address this gap by offering an in-depth assessment of the role of the transport sector in the national economic structure, employing both classical multiplier analysis and exogenous modelling.

3. Methodology and Data Sources

3.1. The Leontief Model and Its Application

Leontief's model, commonly referred to as the input–output model, was developed by Wassily Leontief in the 1930s and further elaborated in subsequent decades (Leontief, 1986). It constitutes a mathematical representation of the structure of a national or regional economy, in which each sector (industry) simultaneously acts as a supplier and a recipient of goods or services in relation to other sectors. A key feature of the I-O model is its ability to depict quantitative intersectoral relationships, which allows analysis of the effects of changes in final demand on the entire economy. The starting point is the input–output table, which reflects the production relationships among individual sectors of the economy (see Table 1).

Table 1.

Input–output transaction table

Sector number i	Intermediate inputs x_{ij}				Final demand Y_i	Total output X_i
	1	2	...	n		
1	x_{11}	x_{12}	...	x_{1n}	Y_1	X_1
2	x_{21}	x_{22}	...	x_{2n}	Y_2	X_2
$\vdots$	$\vdots$	$\vdots$	$\ddots$	$\vdots$	$\vdots$	$\vdots$
n	x_{n1}	x_{n2}	...	x_{nn}	Y_n	X_n
Value added D_j	D_1	D_2	...	D_n		
Total output X_j	X_1	X_2	...	X_n		

Source: the author's own work.

The structure of the Leontief model can be described using two fundamental equations. The first one pertains to the production side (rows of the table) and expresses the total output of the i -th sector as the sum of intermediate inputs delivered to other sectors and final demand:

$$X_i = \sum_{j=1}^n x_{ij} + Y_i \quad (1)$$

where:

X_i – total output of sector i ,

x_{ij} – value of the product from sector i used by sector j as an intermediate input,

Y_i – final demand for the output of sector i (final demand for goods and services of sector i).

$$X_j = \sum_{i=1}^n x_{ij} + D_j \quad (2)$$

where:

X_j – is the total output of sector j ,

x_{ij} – denotes intermediate inputs from sector i used in sector j ,

D_j – primary inputs in sector j , ie, value added (wages, indirect taxes, operating surplus).

On the basis of the values of x_{ij} , one can construct the matrix of technical coefficients A , referred to as the cost structure matrix.

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{n1} & \cdots & a_{nn} \end{bmatrix} \quad (3)$$

The elements of this matrix are nonnegative and represent the cost coefficients (direct input coefficients) of sector j , i.e., the ratio of inputs to outputs in that sector, where:

$$a_{ij} = \frac{x_{ij}}{X_j} \quad i, j = 1, 2 \dots n \quad (4)$$

This formulation allows the model to be transformed into matrix form:

$$X = AX + Y \Leftrightarrow (I - A)X = Y \Leftrightarrow X = (I - A)^{-1}Y \quad (5)$$

where:

X – total output vector,

A – matrix of technical coefficients,

Y – final demand vector,

I – identity matrix,

$(I - A)$ – Leontief matrix,

$(I - A)^{-1}$ – inverse Leontief matrix, representing the total (direct and indirect) impact of final demand on the output of individual sectors.

In the relevant literature, the Leontief model is typically interpreted as a demand-driven model, in which final demand is treated as an exogenous variable, and sectoral output adjusts to its structure and level. In contrast, the supply-driven model (also known as the Ghosh model) starts from value added, which is considered an impulse affecting a sector's ability to produce and supply goods to other sectors (Dietzenbacher, 1997; Lee, Yoo, 2016; Kim, Tromp, 2022). In macroeconomic analysis, the demand-driven approach is much more commonly used,

primarily due to its simplicity and its empirical link to observable demand and consumption variables. This framework helps to understand how increased demand for goods and services in one sector can generate growth impulses throughout the economy. It also enables the identification of sectors that are particularly sensitive to demand-side changes (Fura, 2017), which is crucial for designing regional policies and planning for sustainable development (Chrzanowski, 2014).

The presented structure of the input–output model enables the analysis of the economic structure and the assessment of how changes in final demand affect total sectoral output. Through the technical coefficient matrix, it is possible to trace direct and indirect links between sectors. This model provides a foundation for further analyses of multiplier effects and simulations of changes in the economic structure.

3.2. Indicators of Intersectoral Linkages

To determine the intensity of the transport sector's linkages with other sectors of the economy, backward linkage and forward linkage indicators were used. These are classic measures of sectoral influence in inter-industry analysis. The concepts originate from the work of Rasmussen and Hirschman and are widely applied in studies based on the Leontief model (Miller, Blair, 2009).

Calculations can be performed based on either the matrix of direct technical coefficients A or the full Leontief matrix $L = (I - A)^{-1}$. In this study, the approach based on the matrix L is adopted, as it accounts not only for the direct but also for the indirect effects arising from complex intersectoral linkages. This approach enables a more comprehensive assessment of the structural importance of the analysed sector within the entire production system of the economy.

The backward linkage indicator measures the strength of a given sector's dependence as a recipient of intermediate inputs—specifically, the extent to which the sector relies on products from other sectors in its production process. It is calculated as the sum of values in column j of the Leontief matrix L :

$$BL_j = \sum_{i=1}^n l_{ij} \quad (6)$$

where:

BL_j – backward linkage value for sector j ,

l_{ij} – element of the Leontief matrix L , representing the total impact of sector i on the unit output of sector j ,

n – number of sectors.

The forward linkage indicator determines the extent to which the outputs of a given sector are used by other sectors as intermediate inputs—thereby assessing its importance as a supplier within the economy. It is calculated as the sum of the values in row i of the Leontief matrix L :

$$FL_i = \sum_{j=1}^n l_{ij} \quad (6)$$

where:

FL_i – forward linkage value for sector i .

In this analysis, a normalisation approach was applied, where the results are scaled relative to the economy-wide average. According to the framework presented by Miller and Blair (2009), this allows the indicators to be interpreted in the form of indices:

$$BI_j = \frac{BL_j}{\frac{1}{n} \sum_{j=1}^n BL_j} \quad (7)$$

$$FI_i = \frac{FL_i}{\frac{1}{n} \sum_{i=1}^n FL_i} \quad (8)$$

Values of the indicators above 1 indicate an above-average level of sectoral integration with the economy, whereas values below 1 point to weaker linkages in the respective dimension.

3.3. Multiplier Effects in the Input–Output Model

One of the key applications of the input–output model is the ability to estimate so-called multiplier effects, which reveal the scale of impact that changes in a selected sector have on other parts of the economy. In the context of this study, the goal is to determine the extent to which a change in total output in the transport sector translates into the level of economic activity in other sectors.

According to the classification presented by Miller and Blair (Miller, Blair, 2009), multiplier effects can be divided into:

- Direct effects – the response of the analysed sector to an economic stimulus (e.g., investment).
- Indirect effects – changes in sectors indirectly linked through the supply of intermediate inputs
- Induced effects – further increases in economic activity resulting from higher household incomes and expenditures.

From a mathematical perspective, these multipliers are expressed using the inverse Leontief matrix $(I - A)^{-1}$. The elements of this matrix, denoted as lij , represent the total (direct and indirect) effect of a change in final demand in sector j on the output of sector i . The total output multiplier for sector j is calculated as the sum of the corresponding column in the inverse matrix:

$$m_j^{(X)} = \sum_{i=1}^n l_{ij} \quad (6)$$

where:

$m_j^{(X)}$ – total output multiplier for sector j ,

l_{ij} – element of the inverse Leontief matrix.

Given the availability of satellite coefficients such as the share of value added (d_i), or income (r_i) in the output of a given sector, the corresponding multipliers can be calculated as follows:

– Value-added multiplier:

$$m_j^{(D)} = \sum_{i=1}^n d_i \times l_{ij} \quad (7)$$

– Income multiplier:

$$m_j^{(R)} = \sum_{i=1}^n r_i \times l_{ij} \quad (8)$$

In empirical research, such multipliers make it possible to identify which sectors serve as “engines” of development, exerting a strong influence on the entire economy.

3.4. The Ghosh Supply Model and Supply Multipliers

An alternative to the Leontief demand model is the so-called supply model, also known as the Ghosh model (Dietzenbacher, 1997; Yu, 2018). In contrast to the demand model, which analyses the impact of increased final demand on the entire economy, the supply model focusses on the effects of an increase in total output (supply) in individual sectors. At the core of the model lies the supply allocation coefficient matrix (matrix B), expressed as:

$$B = [b_{ij}] = \left(\frac{z_{ij}}{X_j} \right) \quad (9)$$

where:

z_{ij} – the flow from sector j to sector i ,

X_j – the total output (gross output) of sector j .

The inverse Ghosh matrix $(I - B)^{-1}$ is used to assess the total supply effects, analogously to the Leontief inverse in the demand model (Yu, 2018). The row sum of this matrix for a given sector defines the supply multiplier:

$$m_{s,j} = \sum_{i=1}^n (I - B)^{-1}_{ji} \quad (10)$$

The value of the multiplier reflects the increase in total output across the economy in response to a unitary supply-side impulse in sector j , assuming inelastic final demand.

3.5. The Exogenous Leontief Model with Final Demand Shock Simulation

The classical Leontief demand model assumes that final output (final demand) is the exogenous variable, while sectoral output is an endogenous variable—calculated in response to demand shocks. However, as noted by Miller and Blair (2009), in the case of certain sectors—such as transport—not all output changes result from classical final demand. Infrastructure investments, political decisions, or the development of transport networks may serve as exogenous impulses that trigger changes in other sectors of the economy. For this reason, it is more appropriate to treat the transport sector as a source of economic stimulus that affects other branches of the economy, which constitutes the rationale for adopting an exogenous approach in the present analysis.

In this approach, an extension of the classical input–output (I–O) model is applied, in which the transport sector is treated as an exogenous source of disturbance, and its impact on the national economy is calculated using the inverse Leontief matrix. The change in output in the endogenous (remaining) sectors is expressed by the following equation:

$$\Delta X_e = (I - A)^{-1} A_T \Delta X_T \quad (11)$$

where:

ΔX_e – change in output in the endogenous (remaining) sectors,

A – technical coefficients matrix,

A_T – the column of matrix A representing the demand of individual sectors for the output of the transport sector,

ΔX_T – exogenous change in the output of the transport sector.

The multiplier approach was complemented by an exogenous analysis based on the concept of injecting a unit demand shock into selected sectors. This analysis enables the assessment of the structure of production effects in the remaining sectors of the economy by using the inverse Leontief matrix and multiplying it by a shock vector with a value of PLN 1 million for the selected sector.

3.6. Data Sources

The basis of the analysis consists of input–output tables compiled by Statistics Poland (GUS) for the years 2010, 2015, and 2020, which form an integral part of the national accounts system. The tables containing data for 2010 were prepared in accordance with the SNA 1993 (System of National Accounts) and ESA 1995 (European System of Accounts) standards (GUS, 2014), whereas the tables for 2015 and 2020 were compiled according to the European System of National and Regional Accounts (ESA, 2010), introduced by Regulation (EU) No 549/2013 of the European Parliament and of the Council of 21 May 2013 (GUS, 2019, 2024a), ensuring their comparability at the international level. Moreover, GUS publications provide detailed explanations concerning the methods used to estimate missing data and the principles of

transforming purchaser prices into basic prices, thereby enhancing the transparency and credibility of the analysis.

The input–output tables present the flows of products and services at basic prices, in a product-by-product format, broken down into 77 positions according to the divisions of the Polish Classification of Products and Services (PKWiU). The PKWiU structure is based on the Statistical Classification of Economic Activities in the European Community (NACE), the Classification of Products by Activity (CPA), and the PRODCOM list. The list of 77 ‘branches’ according to PKWiU divisions is provided in the Appendix.

The structure of the input–output tables published by GUS comprises three main segments: the intermediate consumption matrix (Part I), the final demand matrix (Part II), and the gross value added matrix (Part III). In these tables, the transport sector is classified into two subsectors: (1) Land and pipeline transport services (division 49) and (2) Water and air transport services (combined divisions 50 and 51). This classification determined the analytical framework applied in the present study.

GUS also compiles matrices of direct and total technical coefficients of product intensity. These indicators reflect the intensity of intersectoral dependencies within the economy, enabling the analysis of multiplier effects. The methodology used for their calculation is consistent with classical Leontief theory and adapted to the specific characteristics of the Polish economy and statistical classification system. The use of GUS data ensures methodological consistency over time, enabling structural comparisons within the Polish transport sector.

In the present study, the transport sector was examined in a disaggregated manner—both as a whole (combined divisions 49 and 50–51) and separately, i.e., as land and pipeline transport (division 49) and water and air transport (divisions 50–51). This approach enables not only the assessment of the cumulative impact of the entire transport sector on the national economy, allowing for comparison with macro-level analyses (Daldoul, Dakhlaoui, 2025), but also the identification of differences in the structure of multiplier effects generated by individual divisions. It is similar to the methodology applied in studies concerning the economies of Korea (Lee, Yoo, 2016) and Croatia (Vukić, Mikulić, Keček, 2021). As a result, it is possible to indicate both the general role of the transport sector as a driver of economic development and to identify those subsectors that exhibit the strongest links with other branches of the economy and generate the highest indirect and induced effects.

4. Results and Discussion

4.1. Analysis of Intersectoral Linkages of the Transport Sector

As part of the input–output (I-O) analysis, the intensity of the links between the land and pipeline transport sector (division 49) and the water and air transport sector (divisions 50-51) and other branches of the national economy was evaluated. Standard backward linkage (BL) and forward linkage (FL) indicators were applied, in accordance with the Rasmussen–Hirschman methodology, and their values are presented in Tables 2 and 3.

Table 2.
Backward Linkage Indicators for Divisions 49 and 50-51

	Division 49			Divisions 50-51		
Year	2010	2015	2020	2010	2015	2020
Backward linkage	1,7026	1,6841	1,7879	1,8540	1,9434	2,0883
Average (BL)	1,6917	1,6520	1,6559	1,6917	1,6520	1,6559
Backward index (BI)	1,0065	1,0194	1,0798	1,0960	1,1764	1,2612

Source: the author's own work.

The results indicate that both division 49 and divisions 50-51 exhibit backward linkage values above the average, confirming their significant role as recipients of intermediate goods and services. In particular, the increase in the indicator for divisions 50-51 between 2010 and 2020 suggests a growing demand for external resources and a deepening integration with the national economy.

Table 3.
Forward Linkage Indicators for Divisions 49 and 50-51

	Division 49			Divisions 50-51		
Year	2010	2015	2020	2010	2015	2020
Forward linkage	3,9259	4,1231	4,2767	1,2480	1,2286	1,1191
Average (FL)	1,6917	1,6520	1,6559	1,6917	1,6520	1,6559
Forward index (FI)	2,3207	2,4958	2,5828	0,7377	0,7437	0,6758

Source: the author's own work.

The analysis of the forward linkage indicator reveals more pronounced differences. Division 49 consistently achieves index values that exceed 2.3, confirming its importance as a key supplier of services to other sectors. In contrast, water and air transport (divisions 50-51) records values below the average and demonstrates a downward trend, which may indicate a more specialized and limited role within the economic structure.

These results are consistent with the findings of B. Fura (2017). The author–based on aggregated data–classified the transport sector among the group of “key sectors” (BI and FI > 1). Similar conclusions were drawn in studies conducted for Indonesia (Handayani et al., 2020) and Nigeria (Ojaleye, Narayanan, 2022), where transport, treated as an aggregate, was likewise identified as a sector with significant influence on the structure of intersectoral linkages. Similar results were also obtained in analyses conducted for other Central and Eastern

European countries. For example, Balla (2014) analysing the economic sectors of Romania, Hungary and Slovakia based on backward and forward linkage indicators pointed out that in the Slovak economy, the transport and postal services sector ranks second in terms of backward linkage strength. This confirms its strategic importance within the intersectoral structure of the region.

In contrast, detailed analyses conducted in Taiwan (Chiu Lin, 2012), South Korea (Lee, Yoo, 2016), and Tunisia (Daldoul, Dakhlaoui, 2025), which considered the division of transport into rail, road, water, and air subsectors, revealed that the values of both BL and FL indicators for most transport subsectors were below 1. This suggests that in the economies analysed, individual branches of transport did not serve as key nodes in the intersectoral network. Against this background, the transport sector in Poland—particularly land transport—stands out with a consistently high level of integration, both as a recipient and as a supplier, which confirms its systemic importance in the national economy.

4.2. Output, Value Added, Income, and Supply Multipliers of the Transport Sector

At this stage of the analysis, the classical Leontief model was employed to estimate the multipliers of effects generated by the transport sectors in the Polish economy. Four types of multipliers were calculated: output, value added, employment, and income multipliers—in accordance with the methodological approach outlined in Section 3.3. These multipliers illustrate the extent to which an increase in final demand by one unit (PLN 1000) translates into effects throughout the economy. In addition, the supply multiplier based on the Ghosh model, as presented in Section 3.4, was included to capture the impact of a unitary increase in the sector's supply on other branches of the economy. The inclusion of both approaches enables an assessment of the sector's influence from both the demand and supply perspectives.

The results are presented in Table 4 for the two analysed subsectors: division 49 (land and pipeline transport) and divisions 50-51 (water and air transport), across three time periods: 2010, 2015, and 2020.

Table 4.
Output, Value Added, Income, and Supply Multipliers for Transport Sectors

	Division 49			Divisions 50-51		
Year	2010	2015	2010	2015	2010	2015
Output multiplier	1,70	1,68	1,79	1,85	1,94	2,09
Value added multiplier	0,85	0,78	0,92	0,74	0,75	0,66
Income multiplier	0,19	0,15	0,18	1,39	1,56	1,20
Supply multiplier	5,74	5,88	6,23	1,71	1,64	1,75

Note. The output, value added, employment, and income multipliers refer to a unit increase in final demand (PLN 1000), while the supply multiplier reflects the effect of a unit increase in sectoral supply (Ghosh model).

Source: the author's own work.

The analysis of the results reveals differences in economic impacts between the examined divisions as well as clear temporal changes. In the case of division 49, an increase in the output multiplier (from 1.70 to 1.79) and the value added multiplier (from 0.85 to 0.92) was observed. This means that each additional PLN 1000 of final demand in this sector generates PLN 1790 in output and PLN 920 in value added within the economy. The increase in these multipliers indicates rising economic efficiency and stronger linkages of land transport with the national production structure. The results are consistent with the high forward linkage values (Table 2), confirming the significant role of division 49 as a supplier of value to other sectors. On the other hand, the relatively low value of the income multiplier (0.19 in 2010) suggests that income growth in this sector translates only to a limited extent into income increases in other parts of the economy.

For divisions 50-51, an increase in the output multiplier was also observed (from 1.85 to 2.09), along with a consistently high income multiplier (1.39 in 2010, 1.56 in 2015, and 1.20 in 2020). The low and declining value added multiplier (falling from 0.75 to 0.66) may suggest a high share of labour costs and relatively low capital productivity in these divisions. Conversely, the high income multipliers indicate that income growth in these sectors generates significant income effects across other branches of the economy.

The results obtained are consistent with the findings of previous studies, which demonstrated that after 2004, road transport in Poland significantly increased its role as a key component of the logistics system, particularly in the area of freight transport. It became one of the main drivers of efficiency growth in the TSL sector (Fajczak-Kowalska, Kowalska, 2018; Koźlak, 2018), which is reflected in the observed values of the output and value added multipliers.

The importance of transport for the growth of gross output and the generation of value added has also been confirmed in analyses for South Korea (Lee, Yoo, 2016), where particular emphasis was placed on the integration of the transport sector with the manufacturing industry. Kim and Tromp (2022) noted that the logistics sector, including land, water, and air transport, is characterised by strong intersectoral linkages and significant potential to generate production and income effects. Similarly, Kim, Lee, and Trimi (2021) emphasised the systemic function of the logistics sector as a channel for the diffusion of economic impulses. Moreover, the analysis conducted by Zhao and Ding (2024) for China demonstrated high multiplier effects for transport (over 4 for output and around 2 for value added), stemming from its broad interconnections with other sectors of the economy.

The strong linkages between the transport sector and the broader economy imply that disruptions in its functioning can lead to substantial losses in output and income across a wide range of interconnected sectors. This is confirmed by the findings of Ali et al. (2021), which demonstrated that a 21-day transport strike triggered significant economic consequences.

A complement to the demand-side analysis is the supply-driven multiplier, which reflects the capacity of a sector to generate output in other sectors of the economy as a supplier. For division 49, the supply multiplier values range from 5.74 to 6.23, indicating its central role in the supply network. In contrast, for divisions 50-51, these values are significantly lower (1.71-1.75), which may suggest a more limited supply function for this segment of the transport sector.

These findings are consistent with the conclusions of Alises and Vassallo (2016), who, based on data from European economies, argued that the structure of the economy influences the strength of supply-side effects generated by the transport sector. In countries with a higher share of industry, land transport maintains an exceptionally strong position as a supplier of goods and services within the intersectoral system.

4.3. Exogenous Sector Analysis

This subsection presents the results of an input–output analysis using the classical Leontief model in its exogenous formulation. The objective of the analysis was to estimate the impact of an additional demand impulse generated in the transport sector on gross output in other sectors of the national economy. The study was conducted for three time points—2010, 2015, and 2020—which allows for the assessment of structural changes over time and the identification of sectors most sensitive to a demand impulse from the transport sector.

The analysis considered three variants of the demand impulse:

- the impact of division 49 (Land and pipeline transport services),
- the impact of divisions 50-51 (Water and air transport services),
- the cumulative effect for the entire transport sector—divisions 49 and 50-51.

In each case, the demand impulse was set at PLN 1 million (in current prices). Variants 1 and 2 involve a disturbance assigned exclusively to the respective divisions, while in variant 3, the impulse of PLN 1 million impulse was simultaneously assigned to both Division 49 and Divisions 50-51. All other divisions were assigned a disturbance value of zero.

The results are presented as rankings of the ten sectors that, in a given year, recorded the highest output effect in response to the impulse. In this way, the TOP 10 divisions most responsive to the exogenous increase in final demand in the analysed transport divisions are identified. Where a given division did not rank among the ten highest effects in a particular year, the symbol ‘–’ was used, indicating its absence from the TOP 10 list for that year.

Table 5.*Effects of Exogenous Impulse from Division 49*

No.	Description	Code PKWiU	2010		2015		2020	
			Efect	Rank	Efect	Rank	Efect	Rank
1	Land and pipeline transport services	(49)	1 078 597	1	1 107 871	1	1 154 805	1
2	Coke, refined petroleum products	(19)	127 759	2	84 950	2	83 210	3
3	Warehousing; postal and courier services	(52-53)	51 074	3	71 071	3	104 495	2
4	Retail trade services	(47)	41 636	4	29 711	6	23 540	9
5	Sale and repair services of motor vehicles and motorcycles	(45)	39 536	5	28 763	7	24 891	7
6	Electricity, gas, steam and air conditioning	(35)	33 598	6	32 804	4	24 115	8
7	Wholesale trade services	(46)	31 322	7	21 357	10	–	–
8	Motor vehicles	(29)	31 045	8	30 462	5	25 951	6
9	Rental and leasing services	(77)	25 688	9	28 071	8	42 630	5
10	Constructions and construction works	(41-43)	20 396	10	26 246	9	42 815	4
11	Real estate services	(68)	–	–	–	–	20 433	10

Source: the author's own work.

Table 5 presents 11 divisions that recorded the highest output effects in 2010, 2015, and 2020 in response to an exogenous demand impulse directed at division 49 (Land and pipeline transport services). The highest values were observed in the originating division itself (49), confirming its internal importance and strong feedback linkages (intradivisional effects). High and stable positions are held by the divisions of Coke, refined petroleum products (19), Warehousing; postal and courier services (52-53), Electricity, gas, steam and air conditioning (35), as well as Sale and repair services of motor vehicles and motorcycles (45).

Retail trade services (47) deserve particular attention, as they ranked fourth in 2010 but dropped to ninth in 2020, which may indicate a decreasing sensitivity of this division to demand from Land and pipeline transport services. The upward shift in the ranking in 2015 and 2020 of Constructions and construction works (41-43) and Rental and leasing services (77), as well as the appearance of Real estate services (68) in the ranking, reflect changes in the structure of Division 49's impact on other divisions of the economy and growing sensitivity of these divisions to impulses originating from Land and pipeline transport services.

Table 6.*Effects of Exogenous Impulse from Divisions 50-51*

No.	Description	Code PKWiU	2010		2015		2020	
			Efect	Rank	Efect	Rank	Efect	Rank
1	Water and air transport services	(50-51)	1 035 445	1	1 028 194	1	1 044 711	1
2	Warehousing; postal and courier services	(52-53)	263 243	2	302 178	2	271 249	2
3	Rental and leasing services	(77)	54 095	3	63 471	4	85 186	4
4	Coke, refined petroleum products	(19)	54 065	4	34 065	7	48 048	7

Cont. table 6.

5	Repair and installation services of machinery and equipment	(33)	50 974	5	100 828	3	148 231	3
6	Land and pipeline transport services	(49)	46 538	6	54 024	5	58 230	6
7	Constructions and construction works	(41-43)	27 044	7	47 662	6	60 447	5
8	Wholesale trade services	(46)	22 555	8	18 602	8	21 443	9
9	Electricity, gas, steam and air conditioning	(35)	19 654	9	17 605	9	–	–
10	Retail trade services	(47)	18 646	10	–	–	–	–
11	Real estate services	(68)	–	–	17 127	10	24 143	8
12	Food and beverage serving services	(56)	–	–	–	–	21 159	42

Source: the author's own work.

Table 6 presents the ten divisions that recorded the highest output effects in response to an exogenous demand impulse originating from divisions 50-51 (Water and air transport services) in 2010, 2015, and 2020. In all three analysed years, the source division–Water and air transport services (50-51)–consistently ranks first, confirming its high level of self-sufficiency and strong internal feedback effects within the division.

Warehousing; postal and courier services (52–53) consistently hold high positions in the ranking, highlighting their strong operational linkages with transport. Attention should also be drawn to the dynamic increase in the importance of Repair and installation services of machinery and equipment (33), which rose from fifth place in 2010 to third place in 2020, nearly tripling its output effect. Meanwhile, rental and leasing services (77) maintain a stable position (ranked 3rd–4th), which may indicate long-term demand for services supporting transport activities.

Other significant structural changes include the Real Estate Services division (68), which did not appear in the ranking in 2010 but reached tenth and eighth positions in the subsequent years, respectively. In 2020, Food and beverage serving services (56) also appeared in the ranking, which may indicate an increased sensitivity of the food service division to the development of Water and air transport services, particularly in the context of the growing importance of tourism-related linkages with transport.

Table 7.

Effects of Exogenous Impulse from Divisions 49 and 50-51

No.	Description	Code PKWiU	2010		2015		2020	
			Efect	Rank	Efect	Rank	Efect	Rank
1	Land and pipeline transport services	(49)	1125135	1	1161895	1	1213035	1
2	Water and air transport services	(50-51)	1037119	2	1030182	2	1046320	2
3	Warehousing; postal and courier services	(52-53)	314317	3	373249	3	375744	3
4	Coke, refined petroleum products	(19)	181824	4	11915	4	131258	5
5	Rental and leasing services	(77)	79783	5	91542	6	127816	6

Cont. table 7.

6	Repair and installation services of machinery and equipment	(33)	64609	6	113267	5	163203	4
7	Retail trade services	(47)	60282	7	45763	9	39669	10
8	Wholesale trade services	(46)	53877	8	39959	10	39895	9
9	Electricity, gas, steam and air conditioning	(35)	53252	9	50409	8	–	–
10	Sale and repair services of motor vehicles and motorcycles	(45)	48747	10	–	–	–	–
11	Constructions and construction works	(41-43)	–	–	73908	7	103262	7
12	Real estate services	(68)					44617	8

Source: the author's own work.

Table 7 presents the ten divisions that recorded the highest output effects in response to demand impulses introduced jointly to Divisions 49, 50, and 51, treated as a single aggregated transport division. These results extend the analyses presented in Tables 5 and 6, highlighting the synergistic impact of the combined demand impulse on the structure of the national economy.

The source divisions—Land and pipeline transport services (49) and Water and air transport services (50-51)—maintain leading positions in the ranking, confirming the dominant role of transport in the structure of inter-industry linkages. Warehousing; postal and courier services (52-53) consistently holds third place regardless of the year analyzed, underscoring its enduring operational importance for transport activities.

The results presented in Table 7 also reveal the overlapping effects of impulses from both divisions: the Repair and installation services of machinery and equipment division (33), previously present only in the ranking for the impulse in divisions 50-51 (Table 6), rises to fourth place in 2020. Similarly, the Rental and leasing services division (77) maintains a strong position, confirming its universal importance for the operational activities of both branches of transport.

It is also noteworthy that the importance of the Electricity, Gas, Steam and Air Conditioning division (35) and the Retail Trade Services division (47) systematically declined, eventually dropping out of the ranking in 2020. In contrast, the Real estate services division (68), absent in previous years, reached eighth place in 2020, which may indicate increasing sensitivity of this division to demand impulses from the transport sector. It should be noted that this study does not aim to identify the macroeconomic or institutional factors behind the changing sensitivity of individual sectors to transport-induced impulses. Such causal analysis—e.g. related to digitalisation, structural change or urbanization—would require a separate research framework.

The results indicate that exogenous demand impulses generate the strongest output effects within the transport divisions themselves and in directly related divisions, particularly in Warehousing; postal and courier services (52-53). This means that the most substantial effects

are observed within Section H “Transportation and Storage,” confirming the existence of strong intrasectoral linkages in this area. According to the findings of Kim, Lee, and Trimi (2021), transport services, warehousing, and support activities for transportation do not operate as separate units, but rather form a coherent service ecosystem. The results of this study empirically confirm this thesis, indicating systemic interdependencies within Section H.

Studies by Lee and Yoo (2016) and Kim and Tromp (2022) on the South Korean economy demonstrated that demand impulses generated by the transport sector stimulate a range of key economic sectors. In particular, they emphasised the importance of production effects in petroleum and coal refining, the manufacturing of transport equipment, and financial and insurance services. Furthermore, Kim and Tromp (2022) pointed to significant links between road transport and the chemical industry, as well as wholesale and retail trade. In the case of water and air transport, significant interactions are observed in the business support services sector and in the finance and insurance sector. Meanwhile, Daldoul and Dakhlaoui (2025), analysing the effects of transport supply shortages in the Tunisian economy, pointed to the particular vulnerability of sectors such as petroleum refining, the mechanical and electrical industries, and the textile industry. Similar patterns were also noted in the Indonesian economy—Handayani et al. (2020) demonstrated that demand impulses in road and rail transport generate strong production effects in, among others, petroleum refining, retail trade, and warehousing sectors, confirming the international relevance of the phenomenon under study.

Although the structure of secondary effects differs in part from the results observed for Poland, studies conducted in other countries confirm that demand impulses in the transport sector stimulate activity in closely linked sectors. Alises and Vassallo (2016), analysing the cases of Spain and the United Kingdom, demonstrated that the economy’s response to transport-related stimuli depends on the sectoral structure, particularly the share of material-intensive industries that heavily rely on transport services. Similar patterns, though on a smaller scale, were confirmed in a study by Ojaleye and Narayanan (2022) in Nigeria, where transport—although not classified as a key sector, played an important role in transmitting impulses to industries such as trade and construction. The convergence of findings from various countries points to the recurring nature of this mechanism and confirms the importance of transport as a driver of activity in key industrial and service segments.

5. Conclusions, Research Limitations, and Directions for Further Studies

The analysis conducted revealed the complex and dynamic links between the transport sector and other divisions of the national economy. The use of the input–output model enabled the identification of both the structural importance of individual transport subsectors and the directions of their impact on the interindustry system.

Based on the analysis, the following conclusions have been drawn:

- Transport is one of the divisions with a high level of integration with the national economy. It functions both as a significant supplier (forward linkage) and as a recipient (backward linkage) of goods and services, classifying it as a key division in the interindustry framework. Land and pipeline transport services (division 49) are characterised by consistently high backward and forward linkages, confirming their role as a fundamental component of supply chains and a primary provider of logistics services in the Polish economy. In contrast, Water and air transport services (divisions 50-51) demonstrate a lower level of integration with other divisions.
- Both land and pipeline transport services and Water and air transport services exhibited relatively high multiplier effects. This confirms the importance of the transport division as one of the key sources of economic impulses within the inter-industry structure. Furthermore, multiplier effects reveal the growing importance of the transport division as a generator of economic stimuli, particularly in the case of Division 49, whose impact on other divisions has intensified during the period from 2010 to 2020.
- The results of the exogenous effects analysis indicate that demand impulses in the transport division generate intrasectoral effects within the transport divisions themselves and stimulate economic activity primarily in the following divisions: Coke and refined petroleum products (19), Motor vehicles, trailers and semi-trailers (29), Repair and installation services of machinery and equipment (33), Electricity, gas, steam and hot water (35), Constructions and construction works (41-43), Sale and repair services of motor vehicles and motorcycles (45), Wholesale trade services (46), Retail trade services (47), Warehousing; postal and courier services (52-53), Food and beverage serving services (56), Real estate services (68), and Rental and leasing services (77). These effects are comparable to findings from studies conducted in other countries (e.g., South Korea, the United Kingdom, Slovakia, Nigeria), indicating the recurring nature of the transmission mechanism of demand impulses from the transport sector. The shifting positions of specific divisions in the rankings (e.g., the declining importance of energy or retail trade) reflect structural changes in the economy, including digitalisation, the development of integrated services, and changing patterns of transport consumption.
- The Polish economy exhibits structural characteristics similar to those of other industrialised economies, in which transport serves as a catalyst for economic activity.

The conclusions of the analysis confirm the validity of using the input–output approach to assess the role of the transport division, as well as the appropriateness of treating it as a strategic division from a structural perspective. They affirm the systemic role of the transport division in the Polish economy and its importance as a carrier of transformational impulses. This means that the findings of the study are not only of theoretical relevance but also of practical significance. They may serve as a basis for designing measures to support the transport division

as a tool for stimulating economic growth. Especially in the context of investment policy, infrastructure development planning and sectoral programs, it is crucial to treat transport as a systemically important division.

The author acknowledges that the study has certain limitations, which at the same time create opportunities for further analysis. First, due to the lack of complete statistical data, the employment multiplier was not included. Second, the aggregation of applied data into two broad transport categories (Land and Pipeline Transport Services and Water and Air Transport Services) limits the precision in identifying the secondary effects of individual transport branches. Third, the I–O model is static in nature and does not reflect technological, temporal, or price response changes. Fourth, the effects of imports were not considered, which can lead to an overestimation of the secondary effects in the closed model.

Further research should focus on employing a more detailed sectoral classification of transport (e.g., rail, road, air, maritime), applying dynamic models (such as dynamic I–O or CGE models), and incorporating regional differentiation, which may reveal new dependencies in the spatial distribution of secondary effects. It is also worth considering the extension of the analysis to include environmental and social aspects, which are increasingly important in the assessment of transport policies. The use of scenario-based approaches and dynamic models may allow for a more precise evaluation of future development paths for the transport division and its impact on the structure of the national economy. Furthermore, future studies could explore the macroeconomic drivers behind the observed differentiation in sectoral responses to transport-related demand impulses. Analyses linking these variations to broader structural trends—such as digitalisation, urban concentration, or the evolution of service systems—may provide valuable insights into the mechanisms of intersectoral transmission.

In addition, future studies may benefit from the use of modern data sources, including big data (e.g., mobility records, logistics systems, digital platforms), which allow for a more detailed and dynamic assessment of economic responses to transport-related impulses. For studies with a regional focus, spatial analysis tools such as Geographic Information Systems (GIS) could also be applied, particularly in the context of depopulation, transport accessibility, and the territorial variation in the socio-economic effects of transport activity.

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Appendix

Table 8.

List of 77 Divisions According to PKWiU Classification

No.	CODE PKWiU 2008	Description	No.	CODE PKWiU 2008	Description
1	(01)	Products of agriculture and hunting	40	(52-53)	Warehousing; postal and courier services
2	(02)	Products of forestry	41	(55)	Accommodation services
3	(03)	Fish and other fishing products	42	(56)	Food and beverage serving services
4	(05)	Coal and lignite	43	(58)	Publishing services
5	(06-09)	Crude petroleum and natural gas; metal ores; other mining and quarrying products	44	(59)	Motion picture, video and television production, sound recording and music publishing
6	(10)	Food products	45	(60)	Programming and broadcasting services
7	(11)	Beverages	46	(61)	Telecommunications services
8	(12)	Tobacco products	47	(62)	Computer programming, consultancy services
9	(13)	Textiles	48	(63)	Information services
10	(14)	Wearing apparel	49	(64)	Financial services
11	(15)	Leather and related products	50	(65)	Insurance services
12	(16)	Wood and products of wood	51	(66)	Services auxiliary to financ. services and insurance services
13	(17)	Paper and paper products	52	(68)	Real estate services
14	(18)	Printing and recording services	53	(69)	Legal and accounting services
15	(19)	Coke, refined petroleum products	54	(70)	Management consulting services
16	(20)	Chemicals and chemical products	55	(71)	Architectural and engineering services; technical testing and analysis services
17	(21)	Pharmaceutical products	56	(72)	Scientific research and development services
18	(22)	Rubber and plastic products	57	(73)	Advertising and market research services
19	(23)	Other non-metallic mineral products	58	(74)	Other professional, scientific and technical services
20	(24)	Basic metals	59	(75)	Veterinary services
21	(25)	Fabricated metal products	60	(77)	Rental and leasing services
22	(26)	Computer, electronic and optical products	61	(78)	Employment services
23	(27)	Electrical equipment	62	(79)	Travel agency, tour operator and other reservation services and related services
24	(28)	Machinery and equipment n.e.c.	63	(80)	Security and investigation services
25	(29)	Motor vehicles	64	(81)	Services to buildings and landscape
26	(30)	Other transport equipment	65	(82)	Office administrative, office support and other business support services
27	(31)	Furniture	66	(84)	Public administration services
28	(32)	Other manufactured goods	67	(85)	Education services

Cont. table 8.

29	(33)	Repair and installation services of machinery and equipment	68	(86)	Human health services
30	(35)	Electricity, gas, steam and air conditioning	69	(87-88)	Social works services
31	(36)	Natural water; water treatment and supply services	70	(90)	Creative, arts and entertainment services
32	(38)	Waste collection., treatment and disposal services; materials recovery services	71	(91)	Library, archive, museum services
33	(37,39)	Sewerage; remediation services	72	(92)	Gambling and betting services
34	(41-43)	Constructions and construction works	73	(93)	Sporting services and amusement and recreation services
35	(45)	Sale and repair services of motor vehicles and motorcycles	74	(94)	Services furnished by membership organisations
36	(46)	Wholesale trade services	75	(95)	Repair servic. of comput. and personal and household goods
37	(47)	Retail trade services	76	(96)	Other personal services
38	(49)	Land and pipeline transport services	77	(97-98)	Private households with employed persons
39	(50-51)	Water and air transport services			

Source: the author's own work.

RESILIENCE OF THE URBAN LOGISTICS SYSTEM

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Purpose: Cities and regions are currently facing a range of challenges related to natural and civilizational threats. The growing number of threats, as well as the crisis situations that cities have faced in recent years, require the search for mechanisms that enhance their resilience. A cognitive gap in this area concerns the resilience of urban logistics systems. The aim of the research presented in this article is to conceptualize the resilience of a city's logistics system and to highlight the role of stakeholder collaboration in building resilience. Collaboration with stakeholders requires identifying their needs and expectations. The identification of these needs was the objective of empirical research.

Design/methodology/approach: The article analyzes the similarities and differences in the perception of urban logistics system resilience between two stakeholder groups: residents and the volunteer fire department. For this purpose, a questionnaire-based survey was conducted. The results enabled the application of the SERVQUAL method for satisfaction analysis. The final stage of the research involved a risk analysis.

Findings: The research resulted in recommendations for city and regional authorities regarding collaboration with the two studied stakeholder groups to enhance the resilience of cities and regions to threats.

Research limitations/implications: The conducted research focuses on two stakeholder groups and one region. Therefore, it is important to expand the research to include other stakeholder groups and regions.

Originality/value: The development of a construct for the resilience of a city's logistics system and the identification of the role of relational competencies in strengthening resilience.

Keywords: Resilience, logistics system resilience, urban resilience, stakeholders, SERVQUAL, risk analysis.

Category of the paper: Research paper.

1. Introduction

Complex systems, such as urban logistics systems, are highly susceptible to disruptions in the flow of people and goods. Cities that are able to cope with emerging disturbances are considered resilient cities. Resilience is currently a key aspect, also emphasized in the context

of the Fifth Industrial Revolution. The etymological roots of resilience derive from the Latin word *resilio*, meaning “to bounce back” (Klein et al., 2003). As an academic concept, its interpretation is not unambiguous (Adger, 2000) Holling first stated in 1973: Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes and still persist. He paired this notion of resilience with the concept of stability, defined as: „the ability of a system to return to an equilibrium state after a temporary disturbance”. In this context, the article considers the resilience of the city logistics system. The city logistics system consists of the subsystem of freight transport and storage, and the subsystem of passenger transport. Some authors additionally distinguish a subsystem for the movement and storage of waste. There is a lack of publications on a holistic approach to the resilience of urban logistics systems. However, the resilience of logistics systems, as well as urban resilience, are issues addressed by researchers in various contexts. At the same time, publications also appear that deal with the resilience of selected logistics subsystems of a city. These relationships between the concepts that collectively constitute the resilience of the urban logistics system are presented in figure 1.

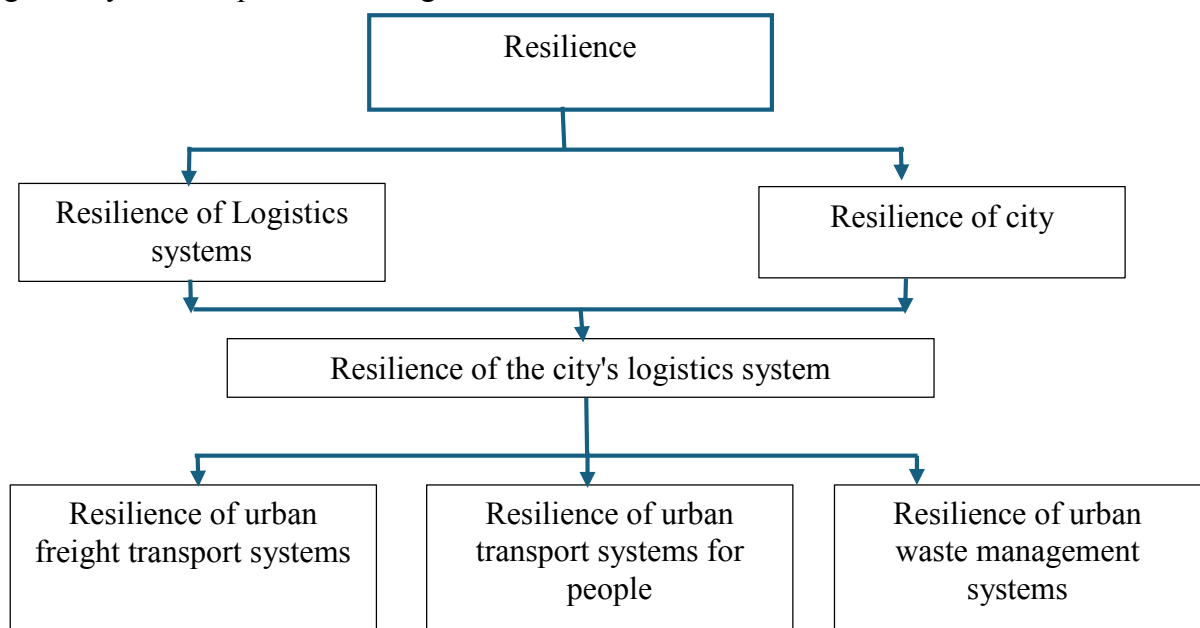


Figure 1. Resilience of the city's logistics system as a component of the city's resilience and the resilience of the logistics system.

Source: own study.

Taking into account these relationships as well as the epistemological gap, the aim of the article is to conceptualize the resilience of the city logistics system to disruptions, especially to natural and anthropogenic threats.

The authors, referring to the stated aim of the article, formulated three research questions:

1. What characteristics should resilient urban logistics systems possess?
2. How do urban logistics stakeholders contribute to building the resilience of the city logistics system?

3. What are the similarities and differences in the perception of factors building the resilience of the city logistics system between two stakeholder groups: residents and members of the Volunteer Fire Department?

To achieve the set aim and obtain answers to the research questions, a literature review was conducted focusing on the construct of logistics system resilience and urban resilience. Subsequently, the methodology for studying factors affecting city resilience was indicated. The methodology included the Servqual method and risk analysis. In the next part, the research results conducted in four municipalities: Olkusz, Bukowno, Bolesław, and Klucze were presented. The conclusions included recommendations for the authorities of the mentioned regions.

2. Resilience and disruptions in the city's logistics system - theoretical background

In interpreting the concept of resilience, disruptions play a key role. In logistics systems, disruptions are interpreted as events that cause deviations in material flows (Peng, 2011). A deviation in a logistics system can include a delayed delivery, an incomplete shipment, a missing delivery, or damaged goods. Therefore, it can be said that disruptions in logistics systems negatively affect the reliability of flow execution (Choi, Chan, 2016). Previous research on disruptions in material flows has led to a classification based on the source of disruption: endogenous and exogenous disruptions (Yang, Pan, Ballot, 2017). Endogenous disruptions originate within the system and can be attributed to a specific participant in the flow. Exogenous disruptions, on the other hand, are independent of the elements within the logistics system and arise from the system's external environment. These include atmospheric factors, natural disasters, and congestion. Processing information about disruptions—meaning the integration of their type, frequency, and effects with the reactions undertaken in response—aims at developing mechanisms to strengthen the resilience of the logistics system. This process makes it possible to determine which actions, under what disruption characteristics, lead to effective outcomes in the form of compensation, elimination, or limitation of disruptions (Kramarz, 2023). The effects of disruptions include the aforementioned deviations in material flows (such as delays or unfulfilled deliveries), but also the consequences of organizational changes (e.g., shifts in order fulfillment priorities, process reorganization, the selection of new participants, and consequently, changes in the costs of logistics processes). Thus, in building logistics system resilience, two disruption compensation variants must be considered. The first variant involves compensation through pre-built mechanisms, such as capacity redundancy, system flexibility, and subcontractor redundancy (Kramarz, 2018). The second variant relates to ex-post operational actions taken after the disruption occurs (Christopher, Towill, 2002).

Both variants can yield relatively similar results in terms of minimizing delays in material flows. However, each requires different resource involvement. Additionally, the second variant involves changes to process organization, which may have delayed effects over time (Sultana et al., 2024).

The vulnerability of a logistics system to disruptions refers to its sensitivity, while the ability to mitigate the negative effects of disruptions is understood as the resilience of that system. A measure of the supply chain's vulnerability is the impact of a given disruption on the achievement of the goals of cooperating organizations. This impact can be assessed in terms of organizational or financial consequences (Romano, 2022). These aspects have been well recognized in the case of logistics systems of production and commercial enterprises, as well as entire supply chains and networks. Transferring these considerations to urban logistics systems requires identifying the characteristics of a city that determine the vulnerability of its logistics system to disruptions. To understand this, one must delve into the concept of „urban resilience”.

Publications on urban resilience discuss issues related to urban policy and spatial planning (Vale, 2014). The socio-environmental resilience of a city can be understood and practiced at various scales and configurations, from individuals to households, communities, neighborhoods, businesses, civil society institutions, governance structures, and infrastructure networks, as well as governance at the local, regional, and national levels, even including multinational regional perspectives.

Defining the context of resilience assessment is a key aspect of research. One possible context is the stakeholder perspective. Mechanisms to enhance resilience will differ depending on whether the focus is on businesses operating in the city or on its residents. In the practice of urban planning, it is emphasized that the goals of ecologists, planners, and economic development researchers are often divergent. The term urban resilience has been adopted by planners and urban designers as a way of describing the ability of cities to respond to systemic threats. However, the concept of resilience also has deep roots in multiple disciplines—from engineering, ecology, and psychology to its growing use in business, economics, information technology networks, and even homeland security. Currently, urban resilience in the literature is most commonly linked to climate change (climate resilience) (Boulanger, 2023; Dhar, Khirfan, 2023), as well as to the impact of the COVID-19 pandemic on urban functioning (Wolniak, 2023).

Urban resilience refers to the capacity of an urban system, including all its social-ecological and socio-technical networks across time and space, to maintain or rapidly return to desired functions in the face of disruptions, to adapt to changes, and to transform systems that limit current or future adaptive capacities. This is a very broad interpretation. Not all authors agree that adaptability is a component of resilience. Another publication emphasized a definition of resilience focused on coping with resource depletion and a changing planet (Zhu et al., 2020).

Urban resilience is also studied by analyzing the ability of designed buildings to withstand terrorist attacks, while other works, such as those focusing on everyday urban resilience, assess a broader set of socio-spatial impacts of counter-terrorism measures on cities. These publications link urban resilience with internal security (Okeke, 2019). As these diverse approaches suggest, a single concept of resilient cities can involve a focus on urban safety, economy, building technology, architecture, anti-terrorism, communities, social capital, natural disasters, and climate change.

Within this diverse, interdisciplinary academic discourse, the following definition becomes useful: “Resilience is the ability of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and thrive no matter what kinds of chronic stresses and acute shocks they experience”. This definition and the accompanying resilience indicator framework were developed by the ARUP International Development Team (2014) in a study commissioned and coordinated by the Rockefeller Foundation. Initially, the research focused on climate resilience and was gradually expanded to a broader view of disaster risk reduction, including financial shocks, terrorism, natural disasters, and critical infrastructure failures, with the overall goal of ensuring urban continuity (ARUP, 2014). One of the main challenges identified was the development of frameworks that allow cities to understand, analyze, and assess resilience (Martin-Breen, Anderies, 2011).

The aim of the ARUP resilience framework is to present a comprehensive, integrated set of indicators and variables. The proposed City Resilience Index serves as a foundation for assessment that enables decision-makers to make better investment decisions and to be more effectively engaged in urban planning practices (ARUP, 2014, p. 21). In this way, seven categories of city system resilience were identified (Table 1).

Table 1.
Key Dimensions of the City Resilience Index

Dimiension	Characteristic
Reflective	Reflective systems are accepting of the inherent and ever-increasing uncertainty and change in today’s world. They have mechanisms to continuously evolve and will modify standards or norms based on emerging evidence, rather than seeking permanent solutions based on the status quo. As a result, people and institutions examine and systematically learn from their past experiences and leverage this learning to inform future decision-making.
Robust	Robust systems include well-conceived, constructed and managed physical assets, so that they can withstand the impacts of hazard events without significant damage or loss of function. Robust design anticipates potential failures in systems, making provision to ensure failure is predictable, safe, and not disproportionate to the cause. Over-reliance on a single asset, cascading failure and design thresholds that might lead to catastrophic collapse if exceeded are actively avoided.
Redundant	Redundancy refers to spare capacity purposely created within systems so that they can accommodate disruption, extreme pressures or surges in demand. It includes diversity: the presence of multiple ways to achieve a given need or fulfil a particular function. Examples include distributed infrastructure networks and resource reserves. Redundancies should be intentional, cost-effective and prioritised at a city-wide scale, and should not be an externality of inefficient design.

Cont. table 1.

Flexible	Flexibility implies that systems can change, evolve and adapt in response to changing circumstances. This may favour decentralised and modular approaches to infrastructure or ecosystem management. Flexibility can be achieved through the introduction of new knowledge and technologies, as needed. It also means considering and incorporating indigenous or traditional knowledge and practices in new ways.
Resourceful	Resourcefulness implies that people and institutions can rapidly find different ways to achieve their goals or meet their needs during a shock or when under stress. This may include investing in capacity to anticipate future conditions, set priorities, and respond, for example, by mobilising and coordinating wider human, financial and physical resources. Resourcefulness is instrumental to a city's ability to restore the functionality of critical systems, potentially under severely constrained conditions.
Inclusive	Inclusion emphasises the need for broad consultation and engagement of communities, including the most vulnerable groups. Addressing the shocks or stresses faced by one sector, location, or community in isolation of others is an anathema to the notion of resilience. An inclusive approach contributes to a sense of shared ownership or a joint vision to build city resilience.
Integrated	Integration and alignment between city systems promotes consistency in decision-making and ensures that all investments are mutually supportive of a common outcome. Integration is evident within and between resilient systems, and across different scales of their operation. Exchange of information between systems enables them to function collectively and respond rapidly through shorter feedback loops throughout the city.

Source: ARUP, 2014, p. 5.

The concept of resilience of urban logistics systems is significantly less recognized. There is a lack of studies in this area, however, the importance of resilience of individual subsystems of urban logistics is being acknowledged. In this respect, the most publications have been devoted to the subsystem of passenger transport. Urban mobility systems consist of various elements that strongly interact with each other. These elements (which may themselves be subsystems) exposed to threats may cause not only unexpected effects in some parts of the system but also threaten the entire functioning of the system. A resilient urban system should be able to withstand serious negative threats while maintaining basic functionality.

In urban transport, the aim of actions increasing resilience is to reduce the effects by maintaining or restoring the normal level of mobility in the shortest possible time, taking into account both passenger and freight transport. Therefore, indicators are an important tool for monitoring the level of resilience. These indicators can be used to compare different regions, which enables the identification of regions that require more attention due to low resilience. (Leobons et al., 2019). Bruneau et al. (2003) presented a resilience framework indicating that resilience could be measured by four determining properties of resilient systems, the 4R structure (Robustness, Redundancy, Resourcefulness, Rapidity). In transport, Robustness reflects the ability of the network and its elements to resist the effects of a disruptive event without significant degradation of the system. Redundancy is the degree to which alternative routes and modes of transport can be used if certain components are damaged; Resources are associated with the availability of materials, consumables, and teams aimed at restoring functionality; Rapidity is the ability to restore functionality in a timely manner, thus resulting from the other three (Tierney, Bruneau, 2007). In this way, redundancy and resources are the "means" of improving resilience, while robustness and rapidity are the desired "goal" of achieving a resilient system (Bruneau et al., 2003; Bruneau, Reinhorn, 2007).

In the context of transport systems, it should be noted that resilience is usually associated with the continuity of the service provided or the restoration of normal functioning after an event. Thus, transport resilience is understood as the ability to maintain mobility at an acceptable level and to recover normal transport operations.

As can be seen, the categories of resilience of logistics systems, city resilience, and resilience of urban transport systems are described with similar measures, especially robust, redundancy, rapid, and resourceful. At the same time, all definitions of resilience are aimed at indicating the impact of disturbances on the functioning of the system and maintaining reliability. The resilience of the urban logistics system will therefore be understood as the ability of the city's logistics system to reliably carry out logistics processes under conditions of endogenous and exogenous disturbances and to restore the system to its original state after disturbances occur.

In building a disruption-resistant urban logistics system, the involvement of urban logistics stakeholders as well as the use of information and communication technologies is necessary. High relational competences are an attribute of an organization that is emphasized in various areas of managing complex systems. In the context of network coordination, it is included in the group of relational mechanisms (Klimas, 2013). Network coordination is, in turn, key in city management and determines its resilience. Relational competences are further strengthened through digital support of relationship management. This issue is especially highlighted by those researchers who conducted studies on city resilience during the Covid-19 pandemic (Lara, et al., 2023). The research showed that the use of digital services, e-tools, remote work, and smart city solutions significantly supplemented policies aimed at pandemic control and helped develop more resilient and environmentally friendly behaviors (Kakderi et al., 2021). After the implementation of actions, the systems gradually resumed activities deemed essential. To strengthen the resilience of cities in the face of the pandemic, Sharifi and Khavarian-Garmsir (2020) also suggested strengthening flow mechanisms, including increasing the space allocated to public transportation and public spaces, as well as implementing intelligent transport systems and sustainable planning of logistics processes in the city. Similar postulates were also indicated by other authors, including Chinazzi et al. (2020), Mahmoudi and Xiong (2022), and Wells et al. (2020). In the indicated publications, a link can be observed between solutions shaping the resilience of the urban logistics system and solutions identified at the highest level of urban logistics maturity.

Taking into account the indicated relational competences as those mechanisms that, through network coordination, influence the resilience of the urban logistics system, the next part of the article focuses on the cooperation of the city with urban logistics stakeholders.

3. Methodology

While conducting research aimed at obtaining answers to the research questions posed in the Introduction, the authors adopted the research methodology presented in Figure 2. It consists of four main stages.

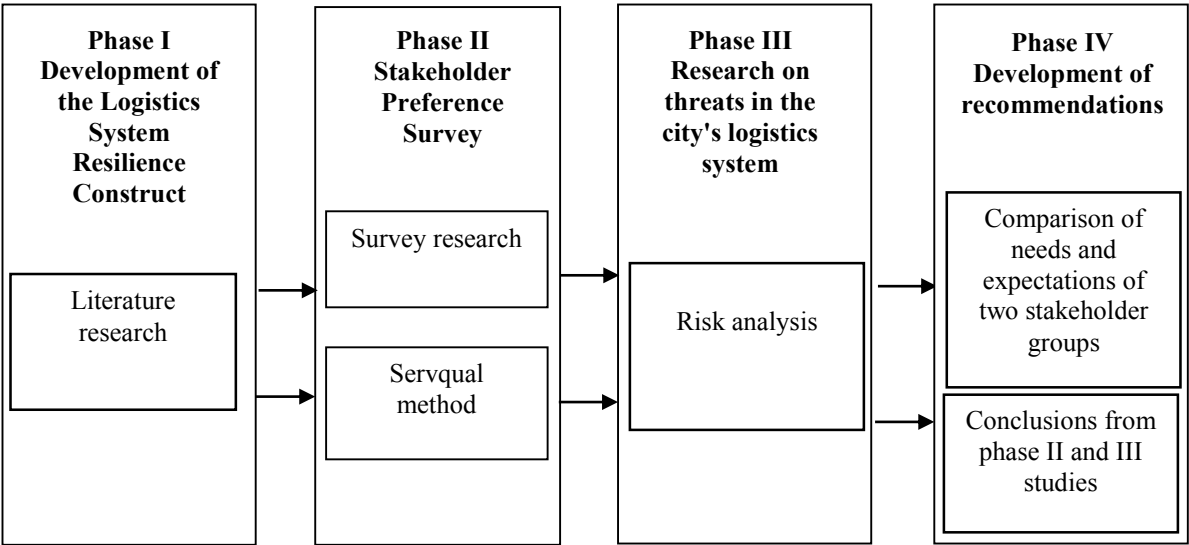


Figure 2. Research methodology

Source: own study.

The Servqual method was used to assess the expectations, feelings and needs of stakeholders. This method is used to assess the quality of services offered by various entities or institutions. The result of the Servqual analysis is a comparison of the expectations of survey respondents with their actual experiences. This allows for an assessment of which areas the surveyed service providers achieve good results and which areas they should work on.

The analysis included two groups of stakeholders: residents of the surveyed areas and firefighters belonging to Volunteer Fire Brigades operating in those areas. The selection of these groups was intentional and justified both methodologically and substantively. Residents constitute a key stakeholder group because they are the direct recipients of public services and the individuals most exposed to the effects of crisis situations. Their sense of security, access to information, as well as the possibility of evacuation or obtaining emergency assistance, reflect the effectiveness of local logistics systems. At the same time, volunteer firefighters are one of the pillars of the response system. They are the first to respond to emergency calls and are among the few who possess practical experience and operational knowledge regarding the effectiveness of local crisis procedures. The relationship between these two groups is not only practical but also systemic. Firefighters are responsible for the safety of residents, while residents are a source of information on the needs and effectiveness of actions taken by the services. Including these two perspectives thus enabled a multidimensional assessment of the resilience of the city's logistics system, both in terms of its functionality and social usefulness.

The first stage of the Servqual analysis involved the creation of questionnaires to assess expected and actual service quality. The questionnaires used a five-point scale, where 1 meant very poor and 5 meant very good. Such a scale enabled the execution of subsequent computational stages of the analysis. The questions in the questionnaire concerned the effectiveness of communication during a crisis, the reliability of the transmitted information, the timeliness and availability of crisis procedures, and the sense of security. Additionally, the questionnaire for firefighters also included questions about crew training levels and the efficiency of rescue equipment. The next step was to assign the questions to dimensions that were modified for the purpose of adapting the method to research on urban logistics systems. The classic Servqual model is based on five fundamental dimensions: tangibles, reliability, responsiveness, assurance, and empathy. Each of these areas refers to a different aspect of the functioning of the surveyed entity, from infrastructure and employee competencies to the effectiveness of response and the ability to understand the user's needs. Due to the specificity of the subject, it was reasonable to modify the classic Servqual categories. In place of the original dimensions, four categories tailored to the context of the analysis were proposed: Information and Communication, Safety and Preparedness, Response and Effectiveness of Actions, and Support and Cooperation.

The next stage involved entering the questionnaire results into a spreadsheet and then calculating the difference between perceived and expected ratings. Based on the obtained differences for each dimension, an arithmetic mean was calculated. The unweighted means thus obtained provided information about the average level of agreement between reality and respondents' expectations in each area. Similarly, an overall unweighted average was calculated, including all questions, which allowed for an evaluation of the system's performance from the perspective of the surveyed group. In the next step, weighted averages were calculated, both at the level of individual dimensions and overall. For this purpose, the researcher assigned each of the four dimensions a weight expressing a subjective assessment of the importance of a given area in the context of effective crisis management and the resilience of urban logistics systems. These weights were set so that their total equaled 1. The use of weighted averages allowed for obtaining results that more accurately reflected the importance of each dimension for the efficiency and resilience of the system, in accordance with the adopted research assumptions.

The final stage of the Servqual analysis conducted within this study involved visualizing the obtained results using graphs and their detailed interpretation. To this end, after calculating the average differences between perceived and expected ratings—both unweighted and weighted—graphical summaries were created for each stakeholder group in the form of bar charts showing quality differences for individual dimensions. The graphical presentation of the results allowed for a clearer depiction of the level of satisfaction (or lack thereof) with the functioning of the logistics system in crisis situations, as well as for quickly identifying the areas with the most significant quality deficits. The charts presented comparisons of average

differences for the four surveyed dimensions, both for residents and for Volunteer Fire Brigade firefighters. Based on the charts, a comparison of the results obtained from both stakeholder groups was made. This analysis revealed significant differences in the perception of the effectiveness of the crisis management system. The results of the Servqual study, conducted separately among residents and representatives of the Volunteer Fire Brigades, made it possible to identify key quality gaps and indicate areas requiring urgent intervention.

According to the adopted research model, the next stage of the conducted research was a risk analysis referring to threats affecting the functioning of the logistics system of the surveyed municipalities in crisis situations. The purpose of this analysis was to determine the level of risk associated with different types of disruptive events that may affect the safety of residents, the availability of public services, transport, and critical infrastructure. This analysis constituted a key diagnostic element for identifying priority areas requiring preventive or remedial actions.

The first stage of the risk analysis was to identify possible threats. Given that the surveyed municipalities struggle with post-mining damage, the threats were adjusted to this aspect and presented in table 2.

Table 2.
List of threats

No.	Threat	Description
1	Terrain deformation (sinkhole) in an urbanized area	Sinks in built-up areas pose a threat to residential buildings, the road network and technical infrastructure. Their sudden appearance can lead to the evacuation of residents and blocking of access to key services. They disrupt the continuity of the urban logistics system.
2	Terrain deformation (sinkhole) in a forest/uninhabited area	Sinks in unbuilt areas do not pose a direct threat to residents but can hinder the operations of rescue services and access to natural resources. If they appear near evacuation routes or service roads, they can cause operational restrictions.
3	Flooding of a main road (treated as flooding)	Flooding of the main communication route results in limited mobility of residents and services, as well as suspension of public transport and supplies. It makes evacuation and access to strategic facilities difficult. It can lead to significant economic losses and delays in the implementation of public services.
4	Occurrence of flooding on the main road	Flooding can cause long-term inaccessibility of the road, destruction of the surface and the need for detours, which extend the response time of the services. It increases the risk of accidents and collisions, especially in the absence of warnings. It makes planning and implementation of logistics routes in the city difficult.
5	Flooding of urbanized areas	Flooding of residential estates directly affects the safety of residents and damages municipal and private infrastructure. It generates a high demand for rescue operations (the need to pump water from basements, for example), social support. In the long term, it affects the quality of life and reduces the value of real estate.
6	Obstruction of evacuation routes	Blocking evacuation routes during a crisis poses a serious threat to the life and health of residents. It makes it difficult for rescue services to reach places at risk. It can lead to organizational chaos and escalation of human and material losses.
7	Damage to the water and sewage network	A failure of the water and sewage network because of flooding or a sinkhole disrupts the supply of drinking water and sewage collection, causing secondary sanitary and epidemiological threats. It affects the functioning of public utility facilities, including schools, hospitals and workplaces. The need to carry out repairs can significantly burden the commune's budget.

Cont. table 2.

8	Flooding/ inundation of an area in an economic zone	Flooding of the economic activity zone results in production downtime, interruptions in supply chains and damage to the assets of enterprises. It entails economic consequences for local companies.
9	Landslide in an economic zone	Landslides can destroy road infrastructure, warehouses or industrial facilities, leading to material losses and job losses. They also threaten the safety of people in these areas. They require geotechnical intervention and temporary exclusion of the area from use. Insufficient or contradictory information increases panic among residents and makes it difficult to make rational decisions. It disrupts communication between services and local authorities, weakening the effectiveness of rescue operations.
10	Lack of information or disinformation during a crisis	Sinks in built-up areas pose a threat to residential buildings, the road network and technical infrastructure. Their sudden appearance can lead to the evacuation of residents and blocking of access to key services. They disrupt the continuity of the urban logistics system.
11	Insufficient number of rescue services	Staff and equipment shortages limit the ability to respond to multiple simultaneous incidents. The time it takes for services to arrive at the stage is longer, which increases the scale of losses and the risk to the lives of residents.
12	Secondary threat, e.g. contamination of groundwater	Secondary effects of the crisis, such as contamination of water intakes, may occur with a delay and remain unnoticed for a longer period. They threaten the health of residents, as well as fauna and flora. They require long-term corrective actions.

Source: own study.

The threats indicated in the table above constitute a list of events that have taken place in the last three years, as well as events that may occur in the near future and pose a real threat to the residents and infrastructure of the discussed communes.

To create a risk matrix, a table was created presenting the probability of the occurrence of a threat on a scale of 1 to 5, where 1 means very low probability, and 5 very high probability of the occurrence of a given risk. The list of probabilities is presented in table 3.

Table 3.
Risk probability scale

Probability	Scale	Description
Very small	1	An event (disturbance) that has a very low probability of occurring (the chance of occurring is between 0% and 20%, e.g. twice a year).
Small	2	An event (disturbance) that has a low probability of occurring (the chance of occurring is between 21% and 40%, e.g. once every 2 months on average).
Medium	3	An event (disturbance) that has a moderate probability of occurring (the chance of occurring is between 41% and 60%, e.g. twice a month on average).
Large	4	An event (disturbance) that has a high probability of occurring (the chance of occurring is between 61% and 80%, e.g. once a week on average).
Very large	5	An event (disturbance) the occurrence of which is associated with a very high probability (the chance of occurrence is between 81% and 100%, e.g. at least twice a week).

Source: own study.

A scale of possible consequences of a given threat that could affect the functioning of the city's logistics system was also created. This table allowed for assigning a numerical value on a scale of 1 to 5 to different levels of consequences of a given event, with the scale reflecting the increasing seriousness of the consequences, from minor disruptions to catastrophic consequences that could lead to paralysis of the transport system, critical infrastructure or rescue services. Table 4 presents the scale of consequences along with their description.

Table 4.
The scale of the risk effect

Effect	Scale	Description
Slight	1	The occurrence of an incident may cause minor, almost imperceptible disruptions to the functioning of the city's logistics system, e.g. short-term difficulties in local traffic or minor problems with access to municipal services. The incident may involve limited losses for residents and local service operators. The impact on the continuity of public transport or the operation of emergency services is minimal and easy to control without major involvement of city resources.
Small	2	The incident causes noticeable, but still limited disruptions to the functioning of the city's logistics system. It may concern, for example, local flooding or temporary difficulties in the logistics service of city facilities, which requires a response from services and intervention by the authorities. The scope of the problem is manageable with the involvement of moderate financial and organizational resources. Residents may feel the effects, but it does not cause long-term paralysis of the infrastructure.
Medium	3	The occurrence of an incident leads to more serious difficulties in the implementation of the basic tasks of the city's logistics system, e.g. disruption of traffic on main communication routes, limited availability of emergency services, or interruptions in the delivery of supplies. It requires coordinated action by city services and engages a significant part of the available resources. Residents and entrepreneurs clearly feel the effects of an event that may negatively affect mobility and safety.
Major	4	An event has a very large impact on the functioning of the city's logistics system. Examples include the closure of key road sections, the collapse or flooding of areas important for the flow of people and goods, or restrictions on the operation of critical infrastructure. The city must engage significant funds and resources to control the situation, and restoring the logistics system to full efficiency requires time and costs. The effects may also include interruptions in the supply of municipal services or the isolation of some areas.
Catastrophic	5	An event leads to a complete disruption of the continuity of the city's logistics system, e.g. interruption of main communication routes, paralysis of emergency services, cutting off districts from infrastructure and resources. The effects are long-term or difficult to reverse, and their removal involves huge financial, time and logistical outlays. The functioning of a city in crisis may be significantly limited or suspended, which affects social and economic life.

Source: own study.

Thanks to this solution, it was possible not only to define the effects of specific threats, but also to compare them in a systemic approach. This table was the basis for building a risk matrix, a tool supporting the process of crisis management and planning preventive actions in urban systems.

As part of the risk analysis conducted within the logistics system of the surveyed municipalities, a list of identified threats was developed, along with assigned values for the probability of occurrence and an assessment of potential consequences. The aim of this analysis was to indicate the most critical factors that could disrupt the continuity of public services, transport infrastructure, and crisis response systems. Table 5 presents twelve key threats that may occur in connection with land deformations, flooding, water accumulation, inefficiencies in the emergency response network, and information-related issues during crisis situations. Each of these threats was assigned a rating in two dimensions: probability and impact. The product of these elements was used to determine the risk level. This result served to assess the degree of threat posed by a given phenomenon to the urban logistics system.

Table 5.
Determining the risk level

No.	Threat	Probability	Scale	Risk level
1	Terrain deformation (sinkhole) in an urbanized area	3	4	12
2	Terrain deformation (sinkhole) in a forest/uninhabited area	4	2	8
3	Flooding of a main road (treated as flooding)	1	4	4
4	Occurrence of flooding on the main road	1	5	5
5	Flooding of urbanized areas	3	4	12
6	Obstruction of evacuation routes	1	4	4
7	Damage to the water and sewage network	1	3	3
8	Flooding/inundation of an area in an economic zone	1	4	4
9	Landslide in an economic zone	2	4	8
10	Lack of information or disinformation during a crisis	4	3	12
11	Insufficient number of rescue services	2	4	8
12	Secondary threat, e.g. contamination of groundwater	3	5	15

Source: own study.

The next stage of conducting the risk analysis was to develop a table describing the risk levels in the context of the functioning of the city's logistics system. Table 6 organizes the risk into four levels, from low to very high, indicating both its acceptability and the consequences for the continuity of city services, infrastructure and coordination of rescue operations. Each level contains a detailed interpretation, thanks to which it was possible to assign appropriate categories to previously identified threats.

Table 61.
Defining risk levels

Risk	Description
Very high risk	This is a completely unacceptable level of risk from the point of view of the functioning of the city's logistics system. It can result in serious disruptions in services for residents, blocking key roads, interruptions in access to public services and hindering the work of rescue services. The consequences require huge financial, organizational and time expenditures, and their elimination can be long-term. In such a situation, it is necessary to immediately implement remedial actions to reduce the threat to an acceptable level and restore the continuity of the city's functioning.
High risk	This is also an unacceptable risk, which can lead to the temporary immobilization of key components of urban infrastructure, such as traffic intersections, economic zones or service junctions. Such disruptions cause difficulties in transport, coordination of rescue operations and in providing basic services to residents. It is recommended to implement comprehensive preventive measures and risk management procedures to limit its impact and enable the maintenance of basic urban functions.
Medium risk	At this level, the risk does not pose a direct threat to the continuity of the city system but can clearly affect the quality and efficiency of city logistics, including the operation of technical services, crisis communication or public information systems. The occurrence of such risks may result in lower social satisfaction and a deterioration of the image of the local government unit. It is necessary to constantly monitor these factors and implement actions to limit their impact on the operational functioning of the city.
Low risk	This is the level of risk considered acceptable in the daily functioning of the city's logistics systems. The potential effects are small and temporary, and their impact does not require serious interventions or reorganization of services. Despite this, it is necessary to conduct constant observation and maintain readiness to act, especially in the event of changes in environmental conditions or the emergence of new risk factors.

Source: own study.

Based on the obtained results, a risk matrix was created, which allows for a graphical arrangement of individual threats depending on their probability of occurrence and the scale of potential effects. Placing threats in the appropriate fields of the matrix allowed for an intuitive determination of which of them require immediate preventive actions and which should only be monitored.

The conducted risk analysis allowed for the identification and assessment of key threats affecting the functioning of logistics systems in the studied municipalities. Both natural events, such as sinkholes, floods or floodlands, and systemic factors, such as disinformation or insufficient number of rescue services, were considered. Based on the developed risk matrix, it was possible to indicate areas requiring urgent intervention and those that should be systematically monitored.

4. Results and discussion

The results of the Servqual analysis conducted among two key stakeholder groups, residents and firefighters of the Volunteer Fire Departments, reveal both similarities and differences in the perception of the quality of the logistics system functioning in crisis situations. Both residents and members of the Volunteer Fire Department assessed the quality of services provided in the areas of: information and communication, safety and preparedness, response and effectiveness of actions, and support and social involvement. Despite the common thematic scope, the results showed different perceptions and priorities of each group.

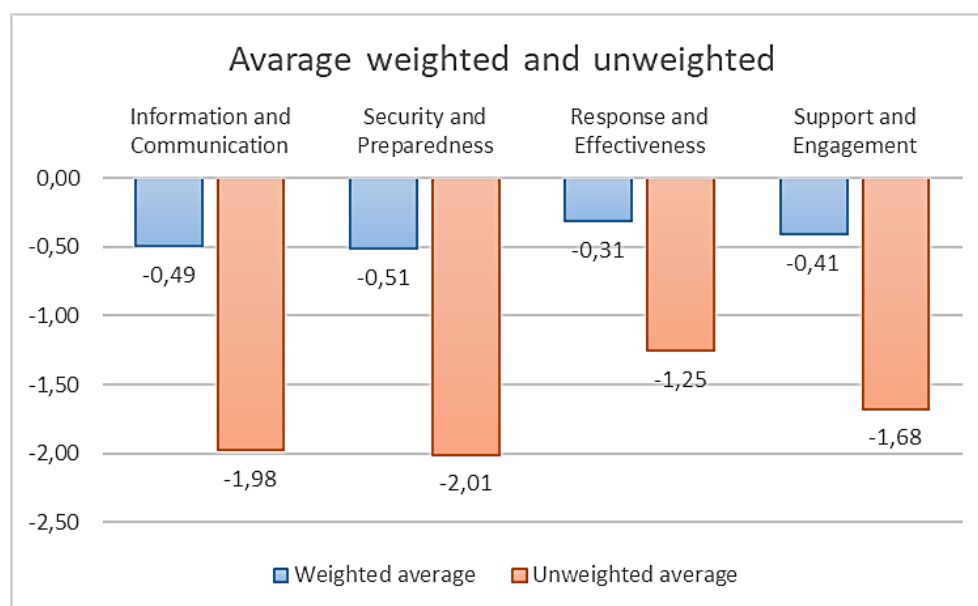


Figure 3. Weighted and unweighted average for residents.

Source: own study.

According to figure 3 for residents, the largest differences between the perceived and expected assessments (both in weighted and unweighted averages) are visible in the dimensions: safety and preparedness (–2.01 unweighted, –0.51 weighted) and information and communication (–1.98 unweighted, –0.49 weighted). This indicates a strong sense of lack of transparency of the authorities' actions, insufficient information about threats and limited access to emergency plans. Residents also show dissatisfaction with the level of safety and feel that local government authorities are insufficiently prepared to deal with crisis situations.

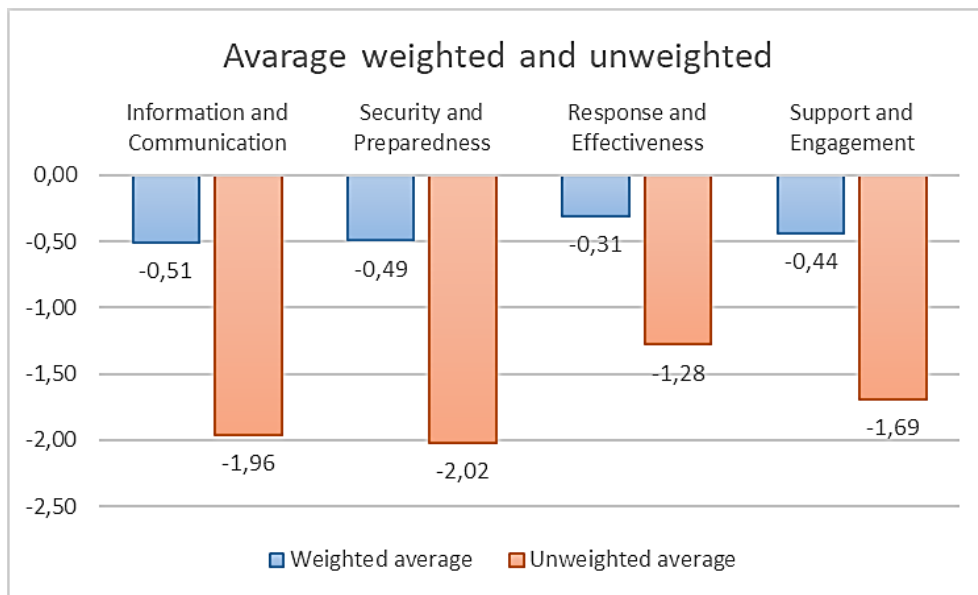


Figure 4. Weighted and unweighted average for OSP.

Source: own study.

Figure 4 shows that OSP firefighters also indicated safety and preparedness (–2.02 unweighted, –0.49 weighted) and information and communication (–1.96 unweighted, –0.51 weighted) as the strongest quality gaps. Although the numerical differences are slightly different than in the case of residents, the data indicate deficiencies in procedures, coordination, and access to current guidelines. OSPs also note a limited level of support and involvement from residents. The differences in mean values (both arithmetic and weighted) show that although both groups recognize the existing deficiencies of the crisis management system, their expectations and assessment of the system's functioning differ slightly depending on the role they play.

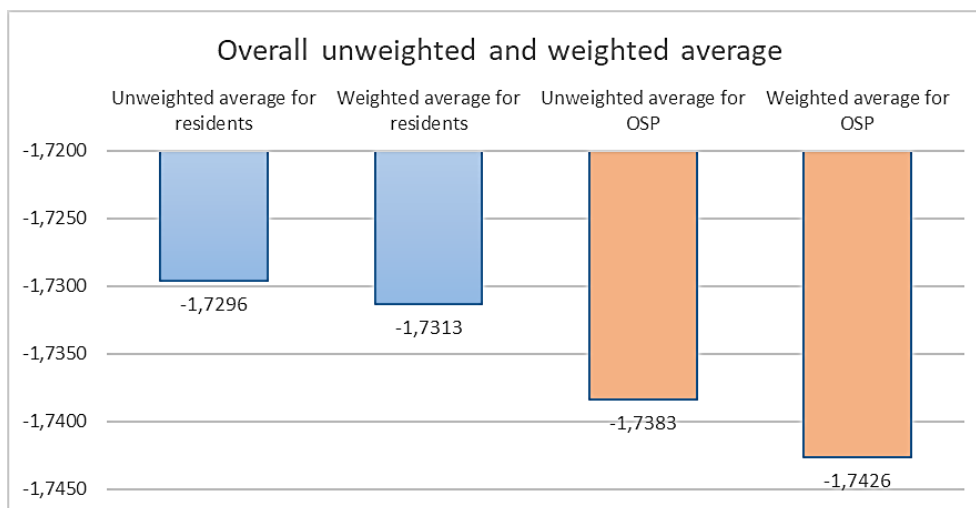


Figure 5. Weighted and unweighted total average.

Source: own study.

In the comparative analysis of Servqual results for the studied groups, both similarities in the level of general dissatisfaction and significant differences in the way of perceiving individual aspects of the quality of crisis management are visible. It is worth paying attention to the values of the general averages, both weighted and unweighted, which are presented in figure 5. In the case of residents, the unweighted average was -1.7296, and the weighted average was -1.7313. In turn, for the OSP firefighters, these values were slightly lower, the unweighted average was -1.7383, and the weighted average was -1.7426. Although these differences are small, it can be seen that firefighters assessed the quality of services related to crisis management slightly more severely. This may result from their daily contact with threats and the operational nature of their work, which allows them to notice more weak points in the operation of the system.

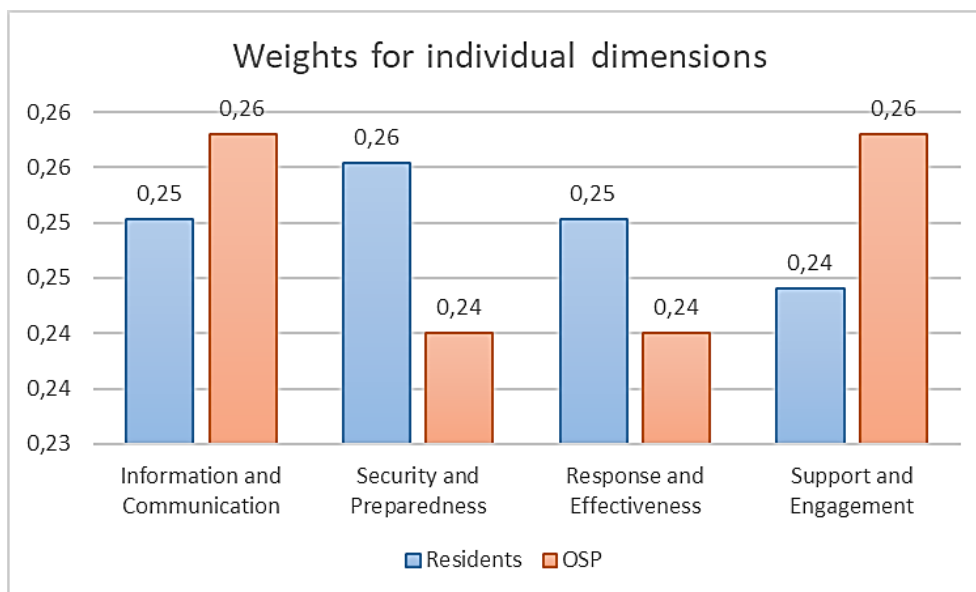


Figure 6. Weights for individual dimensions.

Source: own study.

The differentiation between groups is also visible in the weights assigned to individual assessment areas, as presented in Chart 6. The weights were assigned subjectively, aiming to reflect the dimensions that the surveyed stakeholder groups might emphasize more strongly. For residents, the greatest importance was attributed to the aspect of Safety and Preparedness, reflecting their need for protection during crisis situations and readiness for immediate response. The next most important areas indicated were Response and Effectiveness and Information and Communication, while the least important were Support and Engagement. A different prioritization appeared among firefighters. For them, the highest weights were assigned to the dimensions of Information and Communication and Support and Engagement. This distribution shows that, from their point of view, key elements include efficient information exchange, cooperation between units and residents, and active involvement of the local community in crisis response actions. The lowest weight was assigned to aspects related to safety and preparedness, which results from the fact that they themselves are responsible for these areas and more often notice their systemic limitations.

The results clearly indicate that both the local community and operational units perceive significant shortcomings and deficits in the functioning of the crisis management system, especially in areas related to communication, safety, and operational readiness. Residents of the surveyed areas place particular emphasis on improving the quality of communication with local authorities and increasing the transparency of undertaken actions. They feel a lack in terms of the speed of service response and the availability of emergency plans, which translates into a low sense of security in the face of threats. On the other hand, volunteer firefighters, as individuals responsible for direct response to crisis events, point to the lack of up-to-date operational procedures, insufficient equipment resources, and problems with coordination between units and communication with residents.

The compilation of results from both groups shows that their perspectives are not contradictory but complementary, together forming a complete picture of the needs, expectations, and challenges facing the urban logistics system. The key value of the analysis was the inclusion of both unweighted averages, which show the overall level of satisfaction, and weighted averages, which capture the importance assigned to specific areas. This approach made it possible to identify those elements of the system that are of the greatest importance to stakeholders and which require urgent intervention. The conclusions drawn from the analysis and interpretation of the chart results clearly indicate the need for an integrated approach to crisis management, encompassing not only operational aspects, such as equipping services and improving procedures, but also communication and participatory activities. Only through the combined efforts of authorities, residents, and emergency services can resilient, flexible, and efficient logistics systems be built, capable of effectively responding to disruptions and minimizing their social, economic, and infrastructural impacts.

The conducted risk analysis allowed for the identification and systematization of threats affecting the functioning of urban logistics, with particular attention to the effects resulting from mining activities in the studied areas. The risk assessment was carried out based on a risk matrix, founded on two axes: the probability of threat occurrence and its potential consequences for the logistics system. The matrix is presented in table 7.

Table 7.
Risk matrix

Scale of effect	Catastrophic	5 (Threat.4)	10	15 (Threat.12)	20	25
	Serious	4 (Threat.3, 6, 8)	8 (Threat.9, 11)	12 (Threat.1, 5)	16	20
	Moderate	3 (Threat.7)	6	9	12 (Threat.10)	15
	Small	2	4	6	8 (Threat.2)	10
	Minor	1	2	3	4	5
		Very small	Small	Medium	Large	Very large
		Scale of probability (chance) of occurrence				

Source: own study.

The analysis revealed that out of all the assessed cases, as many as four threats received a very high risk level, indicating their critical importance to the functioning of the municipal logistics system. The most serious identified threat turned out to be secondary contamination of groundwater, which received the highest risk score of 15 points. Although this threat does not occur suddenly, its long-term effects can be difficult to reverse, and their impact on residents health and the natural environment is potentially catastrophic. Almost equally serious were the risks of flooding in urban areas and the occurrence of land deformations (sinkholes) within urban infrastructure. The consequences of these include potential loss of transport infrastructure, threats to residents' health and lives, and the disruption of key communication routes. A high level of risk was also recorded in the case of lack of information or misinformation during crisis situations. Although intangible, this area was assessed as significant from the perspective of crisis management. Inconsistent, incomplete, or false messages can lead to information chaos, reduce the effectiveness of emergency services, and worsen public trust in local authorities. This aspect was highlighted by both residents and firefighters in the conducted surveys. On the other hand, physical risks with lower probability or limited impact, such as land deformations in undeveloped areas, flooding of lower-ranking roads, or landslides outside strategic zones, were assigned medium or low risk levels. However, it should be noted that their occurrence can have a cascading effect, and their cumulative impact may lead to more serious issues within the logistics system, for example, by hindering evacuation or restricting access for emergency services.

The analysis also revealed that systemic threats, including the shortage of emergency resources and the lack of coordinated procedures, represent real barriers to efficient crisis response. An insufficient number of trained personnel and a lack of technical resources confirmed by survey results among volunteer firefighters significantly reduce the operational and logistical efficiency of municipalities during emergencies. The risk matrix became a tool that enabled not only the classification and prioritization of threats, but also the identification of areas requiring immediate remedial action. The analysis confirms the rationale for undertaking preventive measures in areas with the highest risk levels and highlights the need to implement integrated response procedures between emergency units, local administration, and the local community.

5. Conclusions

The issue of urban logistics system resilience in crisis situations, despite its growing importance in the face of climate change, unpredictable environmental hazards, and increasing urban development challenges, remains a relatively underdeveloped area in the academic literature. Studies on urban logistics typically focus on its functionality, efficiency, and management under normal conditions, while knowledge regarding how these systems operate under disruption and what characteristics enhance their resilience to crises is still insufficiently explored. This article addresses that research gap by focusing on the conceptualization of urban logistics resilience and the relational aspects of resilience-building through stakeholder collaboration.

The empirical research conducted provided qualitative data on the perception of logistics system resilience from two selected stakeholder groups: residents and volunteer firefighters (OSP). Conclusions drawn from both analyses were used to formulate practical recommendations for local governments on strengthening the resilience of local systems. However, it is important to highlight certain limitations that affect the generalizability of the results. Firstly, the study was conducted in a single region characterized by specific spatial and environmental conditions linked to mining activity and the consequences of mine closures. As such, the findings may be limited to post-industrial municipalities with similar characteristics, and their application to other regions should be approached with caution. Secondly, the study included only two stakeholder groups. While residents and volunteer firefighters are crucial to the local resilience system, they do not represent the full spectrum of entities involved in urban logistics. Future analyses should be extended to include groups such as: local government and crisis administration officials, employees of municipal utility companies, public transport operators, local entrepreneurs, as well as non-governmental organizations involved in relief efforts.

Moreover, the exclusive reliance on questionnaire-based surveys may be considered a methodological limitation. Although surveys allowed for the collection of comparable data from a large number of respondents, they did not enable an in-depth exploration of the motivations, experiences, and assessments of individual groups. Supplementing the research with interviews, field observations, or stakeholder workshops could enrich the interpretation of results and enhance the exploratory value of the study.

In future research projects, it would also be beneficial to incorporate GIS-based tools. Spatial analysis could help identify critical bottlenecks in transport infrastructure, locations most at risk of disruption to logistics services, or relationships between urban layouts and crisis management effectiveness.

While the current research makes a valuable contribution to the development of knowledge on urban logistics resilience, it remains exploratory in nature due to its limited territorial scope and stakeholder sample. The results obtained may serve as a starting point for more comprehensive research projects that would include a broader range of urban system participants and apply diverse data analysis methods.

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OCCUPATIONAL SAFETY AND HEALTH AS AN AREA OF SCIENTIFIC COGNITION – CURRENT STATUS AND DEVELOPMENT OPPORTUNITIES

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Purpose: The main aim of the research was to analyse the current state and development opportunities of occupational safety and health as an area of scientific cognition in the context of safety engineering.

Design/methodology/approach: The context of safety engineering as a new scientific discipline in the field of engineering and technical sciences creates opportunities for the development of occupational safety and health in the areas of science and education. Selected databases and IT systems operating in the higher education and science system (POL-on; RAD-on; People of Science; Polish Science) were used as sources of information for the research. The website of the Council for Scientific Excellence (RDN) and selected websites of entities (universities, scientific institutes) were used to verify the information.

Findings: Based on research and analyses in the field of occupational safety and health in the aspect of areas of knowledge, education and science, assumptions and an example of synthetic assessment of occupational safety and health in the higher education and science system were proposed. The following information lists were developed: list of universities conducting a field of study, list of entities authorized to award academic degrees in a discipline, list of entities conducting scientific activity in a discipline, list of persons conducting scientific activity in a discipline, list of persons declaring a scientific specialty.

Research limitations/implications: Research and analyses focus on the context of the higher education and science system and selected fields of study dedicated to the occupational safety and health service (occupational safety and health, safety engineering).

Practical implications: The results of research and analyses can be used by entities (universities, scientific institutes) and persons (science managers, academic teachers, students) operating in the higher education and science system, as well as persons professionally involved in occupational safety and health (e.g.: employees of OSH service, lecturers, teachers).

Social implications: The results of research and analyses in the field of occupational safety and health concern the protection of human life and health both in the work environment (occupational) and the public environment (non-occupational).

Originality/value: The publication constitutes a new approach to the areas of occupational safety and health and safety engineering in the context of scientific knowledge in the aspect of the areas of knowledge, education and science.

Keywords: occupational safety and health (OSH), OSH service, safety engineering, higher education and science system, education and science, synthetic assessment.

Category of the paper: research paper, general review.

1. Introduction

Occupational safety and health and the accepted context of knowledge in the field of safety engineering can be considered in different aspects, because they are simultaneously areas of theory (e.g. cognition and discovery) and areas of practice (e.g. action and behavior).

The process of acquiring knowledge includes, among others, division into scientific cognition (objective), that is knowledge based on research and scientific methods, and non-scientific cognition (colloquial, subjective), that is knowledge based on other sources, e.g. personal experience.

The process of scientific cognition is characterized by specific requirements, i.e. standards for conducting scientific research in the fields of science and scientific disciplines (detailed methodology). The general methodology emphasizes, among other things, that scientific cognition is a purposeful and conscious research activity (Apanowicz, 2003), its goal is to solve a research problem, and its key feature is interdisciplinarity (Sadowski, Szydluk, 2016).

The original approach to the scientific cognition process in the field of occupational safety and health problems and the adopted context of safety engineering is the division into three following areas of research and analysis: knowledge, education and science (Krause, 2024c).

Occupational safety and health (EN: OSH or OHS, PL: bhp or BHP) is a popular area of knowledge that applies not only to employees and the work environment (but also to other exposed persons and the non-occupational environment). This concept has reference, among others, to the state security system as the labor protection system (including legal and organizational systems) and the legal system as the labor law (including general, specific and internal law). Who does not know the concept and abbreviation of occupational safety and health or related concepts, e.g.: state of OSH, OSH service, OSH regulations and principles, training in the field of OSH or OHS training?

Occupational safety and health is an area of education in the education system, including the core curriculum for vocational education, the occupation of occupational safety and health and technician (Regulation of the Minister of National Education of 31 March 2017) and initial training and periodic training dedicated to employees at the workplace (Regulation of the Minister of Economy and Labor of 27 July 2004), as well as in the higher education and science system, including qualification requirements dedicated to employees of the occupational safety and health service (Regulation of the Council of Ministers of 2 September 1997): postgraduate study in occupational safety and health, higher study in the field or specialty in occupational safety and health.

Occupational safety and health is not an independent area of science as a scientific discipline, it is a research area and an informal scientific specialty or specialization. The context of safety engineering as a new scientific discipline creates opportunities for the development of occupational safety and health in the areas of knowledge, education and science, in particular in the area of science as a specialty accepted by the scientific community in the higher education and science system, e.g. in promotion procedures (doctor, habilitated doctor, professor).

Safety engineering has been both an area of knowledge and an area of education for at least a dozen or so years, the conventional dates of its contemporary development can be assumed to be the years 2007-2008, in which the following facts were identified: regulations on the education standards were issued (Regulation of the Minister of Science and Higher Education of 12 July 2007), including for the field of study in safety engineering; the field of study in safety engineering was launched (including at the Faculty of Mining and Geology of the Silesian University of Technology); the most frequently cited monograph on the basics of technical safety engineering was published (Pihowicz, 2008).

Safety engineering was not included in the classification of science in Poland when the regulations changed in 2011 (Regulation of the Minister of Science and Higher Education of 8 August 2011) and 2018 (Regulation of the Minister of Science and Higher Education of 20 September 2018). The need to change the classification of science in the aspect of the new discipline of safety engineering was addressed, among others, in the publication (Lustostański, 2016), and the analysis of safety engineering in the aspect of the areas of education and science was presented, among others, in the publication (Krause, 2021b, 2022a).

Safety engineering is a new scientific discipline in the field of engineering and technical sciences, which was introduced in the legal system from November 2022 in connection with the changed classification of science (Regulation of the Minister of Education and Science of 11 October 2022). It began to function in the organizational system from January 2024 based on the results of elections to the Council of Scientific Excellence for the term of office in 2024-2027 (Council for Scientific Excellence, RDN Elections).

The legal basis for the higher education and science system is the fundamental law (Act of 20 July 2018) and implementing acts, including the applicable regulations on the classification of science (Regulation of the Minister of Education and Science of 11 October 2022), and withdrawn, but recommended regulations on the education standards (Regulation of the Minister of Science and Higher Education of 12 July 2007), including the fields of study in occupational safety and health and safety engineering.

This publication is a continuation of previous own research in the field of safety engineering and occupational safety and health, including:

- Assumptions of safety engineering as an area of education, an area of science and a new scientific discipline, e.g.: safety engineering as an area of science and education (Krause, 2021a, 2021b), safety engineering as a scientific discipline and an area of education (Krause, 2022a).
- The higher education and science system in Poland in the aspect of the area of occupational safety and health, discipline of safety engineering and discipline of safety sciences, e.g.: occupational safety and health as an area of knowledge and education (Krause, 2024a), occupational safety and health as an area of safety engineering (Krause, 2024c), safety sciences and safety engineering as areas of science and education (Krause, 2024b).

2. Material and methods

The main aim of the research was to analyse occupational safety and health in the aspect of the new scientific discipline of safety engineering. Based on the literature review and own research, the results of which were included in cyclical reports on the implementation of statutory works (directed research) at the Silesian University of Technology – BK/295/RG-3/2023 (Krause, 2023) and BK-272/RG3/2024 (Krause, 2024d), the following scope of publication was adopted: occupational safety and health as an area of knowledge, occupational safety and health as an area of education, occupational safety and health as an area of science, synthetic assessment of occupational safety and health. The scope of research and analyses in the area of education, due to the adopted context of safety engineering, was limited to the higher education and science system (without the education system) and higher studies (without postgraduate studies).

The research used the document analysis method to collect information (described, among others, in publications (Apanowicz, 2003; Krause, 2018). Publicly available, selected databases and IT systems operating in the higher education and science system) were used as sources of information (POL-on System, Public data; RAD-on System, Data; People of Science Portal; Polish Science Database). The website of central government administration body (Council for Scientific Excellence) and selected websites of entities (universities, scientific institutes) were used to verify and supplement the information.

The following information lists have been developed: list of universities conducting a field of study (RAD-on System, Studies...), list of entities authorized to award academic degrees in a discipline (RAD-on System, Bodies...; Council for Scientific Excellence, Powers ...), list of entities conducting scientific activity in a discipline (RAD-on System, Disciplines...), list of persons conducting scientific activity in a discipline (RAD-on System, Academic...), list of persons declaring a scientific specialty (People of Science Portal; Polish Science Database).

3. Results and discussion

3.1. Occupational safety and health as an area of knowledge

The concept of occupational safety and health has no formal definition adopted in labor law or a generally accepted definition in technical standards or specialist publications. The most frequently cited (although withdrawn) national standard on occupational safety and health management systems (PN-N-18001:2004) includes the following definition: OSH is the state of working conditions and organization and employee behaviors that provide the required level of health and life protection against hazards occurring in the work environment.

Current standards on occupational safety and health management systems – international (PN-EN ISO 45001:2024) and national (PN-N-18002:2011) do not include a definition of occupational safety and health. An example interpretation in the context of OSH management systems could be as follows: OSH is the actions of an organization in order to prevent work-related accidents and diseases and to ensure safe and hygienic workplaces, including process approach based on risk and the PDCA cycle (Krause, 2020).

The concept of safety engineering has no generally accepted definition in legal acts, technical standards and specialist publications. In the literature, the most frequently cited monograph is (Pihowicz, 2008), which contains the following definition: safety engineering arises from the need to solve problems related to the necessity of counteracting hazards caused by technical objects, natural phenomena and human activities in order to rationally maximize the protection of people, the natural environment and the goods of civilization.

Frequently cited monographs in the field of safety engineering include, among others, monographs published in 2008-2009 entitled “Technical safety engineering. Basic problems” (Pihowicz, 2008) and “Reliability and safety” (Szopa, 2009), as well as the latest monographs published in 2020 entitled “Engineering in internal security” (Wolanin, 2020) and “Basics of safety engineering” (Krause, 2020).

Occupational safety and health is a basic area of safety engineering, which is clearly emphasized by, among others, the monograph (Krause, 2020) in the aspect of the adopted conceptual framework and work structure (chapter numbers and titles): safety (2.7. Occupational safety and health), hazard (4.3. Hazards in the work environment), risk (5.4. Occupational risk assessment), accident (6.4. Analysis of accidents at work).

It is necessary to emphasize in the classification of safety engineering the basic criterion of the connection with professional activity, which distinguishes the division into occupational safety engineering and public safety engineering. Occupational safety engineering concerns professional activity, including performing work on the basis of employment relationship, civil law contract and conducting business activity, and the entities are, among others: employed – employee, working person, officer, soldier, entrepreneur – self-employed (Krause, 2020).

Occupational safety and health in the context of safety engineering can be considered, among others, as specific elements of the state's internal security system and the human-technology-environment system (EN: H-T-E, PL: C-T-O). An example interpretation in the context of safety engineering may be as follows: OSH is the creation of the basics for the construction of the labor protection system in the scope of protecting human life and health in the work environment, which includes employees, other working persons and other exposed persons (Krause, 2020).

Occupational safety and health is an area of knowledge that has a direct reference to the labor protection system, which includes, among others, the legal system (including the division into general, industry, specific and internal law) and the organizational system (including the division into state and social supervision and control entities of working conditions and control

and advisory entities acting for the employer). The examples of state supervision and control entities include State Labor Inspection and State Sanitary Inspection, social supervision and control entities include trade unions and social labor inspection, and employer's control and advisory entities include occupational medicine service, occupational safety and health service, and occupational safety and health commission. The adopted scope of the publication focuses on the context of higher studies dedicated to the occupational safety and health service.

Occupational safety and health can also be analyzed in the aspect of the type of information sources, including the following three areas of analysis:

- Legal information as legal information portals, including Online Legal Database (ISAP, Legal information portal) and applicable legal acts, e.g. dedicated to OSH area are section X of the Labor Code Act (Act of 26 June 1974) and basic implementing acts (Regulation of the Minister of Labor and Social Policy of 26 September 1997).
- Standardization information as standardization information portals, including Polish Committee for Standardization (PKN, Standardization information portal) and recommended technical standards, e.g. dedicated to OSH area are standards belonging to the ICS classification (International Classification for Standards) to group no. 13 entitled “Environment – Health Protection – Safety” (PKN, Standards search engine).
- Industry information as recommended achievements of science and technology, including those dedicated to OSH area, are monographs, periodicals and Internet portals, e.g.: State Labor Inspection (PIP, Labor law knowledge portal), Central Institute for Labour Protection – National Research Institute (CIOP-PIB, OSH knowledge Portal), European Agency for Safety and Health at Work (EU-OSHA, OSH knowledge Portal).

Frequently cited theoretical and methodological basics in the field of occupational safety and health (including those related hazards in the work environment and occupational risk assessment) are included, among others, in monographs published by the Central Institute for Labour Protection – National Research Institute, e.g. in the years 1997-1999 “Occupational safety and ergonomics. Volumes I-II” (Koradecka et al., 1997) and “Occupational risk assessment. Methodological basics. Volume 1” (Zawieska et al., 1999), and in the years 2008-2009 “Occupational safety and health” (Koradecka et al., 2008) and “Occupational risk. Methodological basics of assessment” (Zawieska et al., 2009).

Theoretical and methodological basics in the field of occupational safety and health were the subject of numerous original research and analyses, the results of which were published, among others, in the following monographs issued by the Silesian University of Technology in 2018-2023: “Basics of research in the field of occupational safety and health” (Krause, 2018), “Diploma thesis in the field of occupational safety and health” (Krause, 2019), “Research methodology in the field of OSH. Examples of quantitative risk assessment” (Krause, 2022b), “Research methodology in the field of OSH. Examples of quantitative accident forecast” (Krause, Gil, Pelon, 2023).

The current list of monographs in the field of occupational safety and health is presented in the publication (Krause, Salamon, 2024), and the current list of monographs in the field of safety engineering – in the publication (Krause, 2024c).

3.2. Occupational safety and health as an area of education

Occupational safety and health is an area of education in the education system and the higher education and science system. The adopted scope of the publication focuses on the context of the higher education and science system and selected fields of study dedicated to the occupational safety and health service (occupational safety and health, safety engineering).

Occupational safety and health and safety engineering as elements of the higher education and science system have reference, among others, to the following areas of analysis:

- The organizational structure of the units of the higher education and science system, including the names of entities (universities, institutes) and their basic and internal units, e.g.: faculty, institute, department, laboratory.
- Scientific activity (scientific research, development work) conducted in entities (universities, institutes) in the discipline of safety engineering or related disciplines in the specialty in occupational safety and health.
- Teaching activity conducted in the field of higher studies (universities) and postgraduate studies (universities, institutes) includes, among others, teaching that meets the qualification requirements for employees of OSH service.

Higher studies dedicated to OSH service is based, among others, on the education standard for the field of study in occupational safety and health or related fields (including safety engineering). Qualifying studies are conducted in the field of study or specialty of education in the field of occupational safety and health, and include the following types of studies: level of education (first-cycle, second-cycle), profile of study (general academic, practical), form of studies (full-time, part-time).

If higher studies are conducted field of study without specialty of education in the field of occupational safety and health, then, at the request of the graduate, the university makes an entry in the diploma supplement about obtaining qualifications in the field of OSH service on the basis of curriculum covering the content and outcomes of education in the field of occupational safety and health.

The list of universities conducting field of study in occupational safety and health or related fields in the aspect of the level of education and profile of study (only conducted studies) is presented in Tables 1 and 2.

Table 1.

List of universities conducting field of study in occupational safety and health or related fields in the aspect of the level of education and profile of study

Name of the university	Name of the field of study	Type of studies	
		level of education	profile of study
Academy of Applied Sciences of the Association for Adult Education in Szczecin	occupational safety and health	I	P
Białystok School of Economics	occupational safety and health	I	P
Casimir Pulaski Radom University	occupational safety and health	I	P
	occupational safety and health	II	P
Cuiavian University in Włocławek	occupational safety and health	I	P
Częstochowa University of Technology	occupational safety and health	I	O
	occupational safety and health	II	O
Fire University	occupational safety and health	I	P
	occupational safety and health	II	P
Higher Engineering School of Safety and Labor Organization in Radom	occupational safety and health	I	P
Higher School of Pedagogics and Technology in Konin	occupational safety and health	I	P
Humanitas University in Sosnowiec	occupational safety and health	I	P
Kazimierz Wielki University	occupational safety and health	I	O
	occupational safety and health	I	P
Medical University of Gdańsk	environmental health and occupational safety and health	II	O
Medical University of Silesia in Katowice	occupational safety and health – protection of workers' health	I	O
Private College of Environmental Protection in Radom	occupational safety and health	I	P
Professor Edward Lipinski Academy of Applied Sciences	occupational safety and health	I	P
University of Life Sciences in Lublin	occupational safety and health	I	O
	occupational safety and health	II	O
University of Zielona Góra	occupational safety and health	I	O
	occupational safety and health	II	O
Wrocław University of Technology	occupational safety and health	II	O
WSB Merito University in Gdansk	occupational safety and health	I	P

Marks (PL): I – first-cycle study, II – second-cycle study, O – general academic profile, P – practical profile.

Source: own study based on data (RAD-on System, Studies...).

Selected results of the analysis of universities conducting field of study in occupational safety and health or related fields: The field of study is offered at 18 universities – 9 public universities (6 universities, 2 technical universities, 1 uniformed services university) and 9 private universities (5 higher schools, 4 universities and academies). The field of study is offered at 24 types of studies – 17 first-cycle studies and 7 second-cycle studies, no long-cycle master's studies in the list; 14 studies with practical profile and 10 studies with general academic profile. Field of study assigned to 9 scientific disciplines as leading disciplines – 11 types of studies in 4 disciplines of engineering and technical sciences (5 environmental engineering, mining and energy, 2 each of chemical engineering, materials engineering and mechanical engineering), 8 types of studies in 2 disciplines of social sciences (5 safety sciences, 3 management and quality sciences), other disciplines: 2 health sciences, 2 animal sciences and fisheries, 1 legal sciences.

Table 2.

List of universities conducting field of study in safety engineering or related fields in the aspect of the level of education and profile of studies

Name of the university	Name of the field of study	Type of studies	
		level of education	profile of study
AGH University of Krakow	safety engineering	II	O
Cracow University of Technology	safety engineering	I	O
Fire University	safety engineering	I	O
	safety engineering	II	O
	safety engineering	JM	O
General Tadeusz Kościuszko Military University of Land Forces	safety engineering	I	P
	safety engineering	II	P
	safety engineering	JM	P
Jan Długosz University in Czeszochowa	safety engineering	I	P
	safety engineering	II	P
Kazimierz Wielki University	safety engineering	I	P
Kielce University of Technology	safety engineering	I	O
Lodz University of Technology	occupational safety engineering	I	O
Lublin University of Technology	safety engineering	I	P
Military University of Technology	safety engineering	I	O
	safety engineering	II	O
	safety engineering	JM	O
Opole University of Technology	safety engineering	I	O
Polish Air Force University	air safety engineering	JM	P
Poznań University of Technology	safety engineering	I	O
	safety engineering	II	O
	safety engineering and quality	I	O
	safety engineering and quality	II	O
Silesian University of Technology	safety engineering	I	O
	safety engineering	II	O
University of the National Education Commission	safety engineering	I	P
	safety engineering	II	P
West Pomeranian University of Technology in Szczecin	technical safety	I	O
Wrocław University of Environmental and Life Sciences	safety engineering	I	O
	safety engineering	II	O

Marks (PL): I – first-cycle study, II – second-cycle study, JM – long-cycle master's study, O – general academic profile, P – practical profile.

Source: own study based on data (RAD-on System, Studies...).

Selected results of the analysis of universities conducting field of study in safety engineering or related fields: Field of study is offered at 17 universities – only 17 public universities (9 technical universities, 4 universities, 4 uniformed service universities), no of private universities in the list. Field of study is offered at 30 types of studies – 16 first-cycle studies, 10 second-cycle studies, 4 long-cycle master's studies; 20 studies with general academic profile and 10 studies with practical profile. Field of study assigned to 7 scientific disciplines as leading disciplines – 22 types of studies in 5 disciplines of engineering and technical sciences (8 environmental engineering, mining and energy, 7 mechanical engineering, 4 civil engineering, geodesy and transport, 2 safety engineering, 1 chemical engineering), 8 types of studies in 2 disciplines of social sciences (4 each of safety sciences and management and quality sciences).

The list of universities conducting higher studies dedicated to OSH service in the field of study in occupational safety and health or related fields and safety engineering or related fields (only conducted studies) is presented in Tables 3 and 4.

Table 3.

List of universities conducting higher studies dedicated to the occupational safety and health service in the field of study in occupational safety and health or related fields

Name of the university	Name of the field of study (level of education)	Field of study	
		without specialty	with specialty
Academy of Applied Sciences of the Association for Adult Education in Szczecin	occupational safety and health (first-cycle)		YES
Bialystok School of Economics	occupational safety and health (first-cycle)	YES	
Casimir Pulaski Radom University	occupational safety and health (first-cycle)	YES	
	occupational safety and health (second-cycle)	YES	
Cuiavian University in Włocławek	occupational safety and health (first-cycle)		YES
Częstochowa University of Technology	occupational safety and health (first-cycle)		YES
	occupational safety and health (second-cycle)		YES
Fire University	occupational safety and health (first-cycle)	YES	
	occupational safety and health (second-cycle)	YES	
Higher Engineering School of Safety and Labor Organization in Radom	occupational safety and health (first-cycle)	YES	
Higher School of Pedagogics and Technology in Konin	occupational safety and health (first-cycle)		YES
Humanitas University in Sosnowiec	occupational safety and health (first-cycle)		YES
Kazimierz Wielki University	occupational safety and health (first-cycle, general academic profile)	YES	
	occupational safety and health (first-cycle, practical profile)	YES	
Medical University of Gdańsk	environmental health and occupational safety and health (second-cycle)	YES	
Medical University of Silesia in Katowice	occupational safety and health – protection of workers' health (first-cycle)	YES	
Private College of Environmental Protection in Radom	occupational safety and health (first-cycle)	YES	
Professor Edward Lipinski Academy of Applied Sciences	occupational safety and health (first-cycle)	YES	
University of Life Sciences in Lublin	occupational safety and health (first-cycle)	YES	
	occupational safety and health (second-cycle)	YES	

Cont. table 3.

University of Zielona Góra	occupational safety and health (first-cycle)	YES	
	occupational safety and health (second-cycle)	YES	
Wrocław University of Technology	occupational safety and health (second-cycle)		YES
WSB Merito University in Gdansk	occupational safety and health (first-cycle)		YES

Source: own study based on data (RAD-on System, Studies...) and selected websites of universities.

Table 4.

List of universities conducting higher studies dedicated to the occupational safety and health service in the field of study in safety engineering or related fields

Name of the university	Name of the field of study (level of education)	Field of study	
		without specialty	without specialty
AGH University of Krakow	safety engineering (second-cycle)		YES
Cracow University of Technology	safety engineering (first-cycle)	YES	
Jan Długosz University in Czeszochowa	safety engineering (first-cycle)		YES
Kielce University of Technology	safety engineering (first-cycle)		YES
Lodz University of Technology	occupational safety engineering (first-cycle)	YES	
Lublin University of Technology	safety engineering (first-cycle)	YES	
Opole University of Technology	safety engineering (first-cycle)		YES
Poznań University of Technology	safety engineering (first-cycle)	YES	
	safety engineering (second-cycle)		YES
	safety engineering and quality (first-cycle)	YES	
	safety engineering and quality (second-cycle)		YES
Silesian University of Technology	safety engineering (first-cycle)		YES
	safety engineering (second-cycle)		YES
University of the National Education Commission	safety engineering (second-cycle)		YES
West Pomeranian University of Technology in Szczecin	technical safety (first-cycle)		YES
Wrocław University of Environmental and Life Sciences	safety engineering (first-cycle)	YES	
	safety engineering (second-cycle)		YES

Source: own study based on data (RAD-on System, Studies...) and selected websites of universities.

Selected results of the analysis of universities conducting higher studies dedicated to OSH service in the field of study in occupational safety and health or related fields: The field of study is offered at 18 universities and 24 types of studies. The field of study is offered at 16 types of studies without specialty and 8 types of studies with 20 specialties. The field of study without specialty of education is offered at 11 universities: 7 public universities (6 universities, 1 uniformed services university), 4 private universities (3 higher schools, 1 academy). The field of study with specialty of education is offered at 7 universities: 5 private universities (3 universities and academies, 2 higher schools), 2 public universities (only 2 technical universities).

Selected results of the analysis of universities conducting higher studies dedicated to OSH service in the field of study in safety engineering or related fields: The field of study is offered at 12 universities and 17 types of studies (out of 17 universities and 30 types of studies). The field of study is offered at 6 types of studies without specialty and 11 types of studies with 13 specialties. The field of study without specialty of education is offered at 3 public universities (only 3 technical universities). The field of study with specialty of education is offered at 7 public universities (5 technical universities, 2 universities). The field of study with and without specialty of education is offered at 2 public universities (1 university, 1 technical university).

Universities conducting higher studies dedicated to OSH service in the fields of study in occupational safety and health and safety engineering can be divided into the following groups of entities of the higher education and science system:

- 11 technical universities: polytechnics (Cracow University of Technology, Częstochowa University of Technology, Kielce University of Technology, Lodz University of Technology, Lublin University of Technology, Opole University of Technology, Poznań University of Technology, Silesian University of Technology, Wrocław University of Technology), other universities (AGH University of Krakow, West Pomeranian University of Technology in Szczecin).
- 10 public universities: uniformed services university (Fire University), medical universities (Medical University of Gdańsk, Medical University of Silesia in Katowice), other universities (Casimir Pulaski Radom University, Jan Długosz University in Czeszochowa, Kazimierz Wielki University, University of Life Sciences in Lublin, University of the National Education Commission, University of Zielona Góra, Wrocław University of Environmental and Life Sciences).
- 9 private higher school: universities and academies (Academy of Applied Sciences of the Association for Adult Education in Szczecin, Humanitas University in Sosnowiec, Professor Edward Lipinski Academy of Applied Sciences, WSB Merito University in Gdansk), other higher school (Białystok School of Economics, Cuiavian University in Włocławek, Higher Engineering School of Safety and Labor Organization in Radom, Higher School of Pedagogics and Technology in Konin, Private College of Environmental Protection in Radom).

The analysis covered only two fields of study dedicated to the occupational safety and health service: occupational safety and health, safety engineering.

3.3. Occupational safety and health as an area of science

Occupational safety and health is a research area, but it is not an independent area of science as a scientific discipline. According to the changed classification of science in Poland, safety engineering is a new scientific discipline in the field of engineering and technical sciences (Regulation of the Minister of Education and Science of 11 October 2022). The adopted scope

of the publication focuses on the analysis of occupational safety and health in the context of safety engineering or related disciplines.

In accordance with the Resolution of the Council for Scientific Excellence of 13 February 2023 on changes in the classification of scientific fields and disciplines (Council for Scientific Excellence, Announcement No. 3/2023) safety engineering was separated from the disciplines of engineering and technical sciences (architecture and urban planning, automation, electronics and electrical engineering, information and communication technology, biomedical engineering, chemical engineering, civil engineering and transport, materials engineering, mechanical engineering, environmental engineering, mining and energy), social sciences (economics and finance, safety sciences, management and quality sciences) and other fields of science (computer science, biological sciences, chemical sciences, physical sciences, earth and environmental sciences, food and nutrition technology).

The list of entities and number of people conducting scientific activity in the discipline of safety engineering in the aspect of academic title or degree (only persons with at least a doctoral degree and current employment as their primary place of work) is presented in Table 5.

Universities and scientific institutes conducting scientific activity in the discipline of safety engineering can be divided into the following groups of entities of the higher education and science system:

- 5 entities employing at least 12 people: scientific institutes (Military Institute of Armament Technology, Scientific and Academic Computer Network – National Research Institute), uniformed services universities (General Tadeusz Kościuszko Military University of Land Forces, Fire University), private university (WSB University).
- 6 entities employing from 2 to 11 people: uniformed services university (Military University of Technology), technical universities (Cracow University of Technology, Częstochowa University of Technology, Poznań University of Technology), public universities (Warsaw University of Life Sciences, Wrocław University of Environmental and Life Sciences).
- 7 entities employing 1 person: scientific institutes (Central Institute for Labour Protection – National Research Institute, Military Institute of Engineering Technology named after Professor Józef Kosacki), technical universities (Koszalin University of Technology, Silesian University of Technology, Warsaw University of Technology), public university (Gdynia Maritime University), private university (Polish-Japanese Academy of Information Technology).

Table 5.

List of entities and number of people conducting scientific activity in the discipline of safety engineering in the aspect of academic title or degree

The employing entity	Academic title or degree			Sum
	Prof.	DSc	PhD	
Central Institute for Labour Protection – National Research Institute ¹	0	0	1	1
Cracow University of Technology	1	0	1	2
Częstochowa University of Technology ¹	1	2	1	4
Fire University	2	12	20	34
Gdynia Maritime University	0	1	0	1
General Tadeusz Kościuszko Military University of Land Forces	1	2	9	12
Koszalin University of Technology	0	0	1	1
Military Institute of Armament Technology	2	1	18	21
Military Institute of Engineering Technology named after Professor Józef Kosacki ¹	0	0	1	1
Military University of Technology	0	0	2	2
Polish-Japanese Academy of Information Technology ¹	0	0	1	1
Poznań University of Technology	0	1	1	2
Scientific and Academic Computer Network – National Research Institute	2	2	12	16
Silesian University of Technology	0	1	0	1
Warsaw University of Life Sciences ¹	0	5	2	7
Warsaw University of Technology ¹	1	0	0	1
Wrocław University of Environmental and Life Sciences	0	4	1	5
WSB University	4	7	5	16
Sum	14	38	76	128

Marks: ¹ university not included in the list of entities conducting scientific activity in the discipline of safety engineering (RAD-on System, Disciplines...).

Source: own study based on data (RAD-on System, Disciplines...; RAD-on System, Academic...).

Conducting scientific activity in the discipline of safety engineering was declared by 128 people with at least a doctoral degree and current employment as their primary place of work:

- people with the academic title of professor (14, 10.9% share), including: WSB University (4), Fire University (2), Military Institute of Armament Technology (2), Scientific and Academic Computer Network – National Research Institute (2).
- persons with the academic degree of habilitated doctor (38, 29.7% share), including: Fire University (12), WSB University (7), Warsaw University of Life Sciences (5), Wrocław University of Environmental and Life Sciences (4).
- people with a doctoral degree (76, 59.4% share), including: Fire University (20), Military Institute of Armament Technology (18), Scientific and Academic Computer Network – National Research Institute (12), General Tadeusz Kościuszko Military University of Land Forces (9), WSB University (5).

The largest number of people conducting scientific activity in the discipline of safety engineering was identified in the following entities (total number of people and number of independent scientists): Fire University (34 and 14), WSB University (16 and 11), Scientific and Academic Computer Network – National Research Institute (16 and 4), Military Institute of Armament Technology (21 and 3), General Tadeusz Kościuszko Military University of Land Forces (12 and 3), Warsaw University of Life Sciences (7 and 5), Wrocław University of

Environmental and Life Sciences (5 and 4), Częstochowa University of Technology (4 and 3).

Based on our own research (Krause, 2023; Krause, 2024d), the list of specialties was proposed for the analysis of occupational safety and health in the aspect of the area of science.

The proposal for the analysis of occupational safety and health in the aspect of areas of science includes the following scientific specialties:

- Occupational safety and health (OSH) as the leading specialty (occupational safety, occupational hygiene).
- Related specialties: occupational safety and health in mining (occupational safety in mining), occupational safety and health management systems (occupational safety and health management, occupational safety management), ergonomics in the aspect of working conditions (e.g.: ergonomics, biomechanics, occupational physiology, occupational psychology).

The list of entities and number of persons declaring scientific specialty in occupational safety and health or related specialties in the aspect of academic title or degree (only persons with at least a doctoral degree and current employment as their primary place of work) is presented in Table 6.

Universities and scientific institutes employing persons declaring scientific specialty in occupational safety and health or related specialties can be divided into the following groups of entities of the higher education and science system:

- 5 entities employing at least 5 people: scientific institutes (Central Institute for Labour Protection – National Research Institute, Central Mining Institute – National Research Institute), technical universities (Poznań University of Technology, Silesian University of Technology, Wrocław University of Technology).
- 13 entities employing 2 to 4 people: scientific institutes (KOMAG Institute of Mining Technology, Nofer Institute of Occupational Medicine), technical universities (Częstochowa University of Technology, Gdańsk University of Technology, Łódź University of Technology, Warsaw University of Technology), public universities (Casimir Pulaski Radom University, Jagiellonian University in Kraków, Poznań University of Life Sciences, University of Agriculture in Kraków, University of Bielsko-Biala, University of Zielona Góra), private university (University of Technology and Arts in Applied Sciences in Warsaw).
- 24 entities employing 1 person, including scientific institutes, public and private universities, np.: AGH University of Kraków, Białystok University of Technology, General Karol Kaczkowski Military Institute of Hygiene and Epidemiology, General Tadeusz Kościuszko Military University of Land Forces, Higher Engineering School of Safety and Labor Organization in Radom, Humanitas University in Sosnowiec, Jan Długosz University in Częstochowa, Koszalin University of Technology, Lublin University of Technology, Medical University of Silesia, Poznań University of Economics and Business, Scientific and Research Centre for Fire Protection – National

Research Institute, University of Occupational Safety Management in Katowice, University of Security in Poznań, Warsaw University of Life Sciences, Wrocław University of Environmental and Life Science).

Table 6.

List of entities and number of persons declaring scientific specialty in occupational safety and health or related specialties in the aspect of academic title or degree

The employing entity	Academic title or degree			Sum
	Prof.	DSc	PhD	
Casimir Pulaski Radom University	1	1	0	2
Central Institute for Labour Protection – National Research Institute	0	5	4	9
Central Mining Institute – National Research Institute	1	3	2	6
Częstochowa University of Technology	0	1	3	4
Gdańsk University of Technology	1	0	1	2
Jagiellonian University in Kraków	0	2	0	2
KOMAG Institute of Mining Technology	0	0	2	2
Lodz University of Technology	0	1	3	4
Nofer Institute of Occupational Medicine	0	1	1	2
Poznań University of Life Sciences	0	2	0	2
Poznań University of Technology	0	4	4	8
Silesian University of Technology	1	4	11	16
University of Agriculture in Krakow	1	2	0	3
University of Bielsko-Biala	1	2	0	3
University of Technology and Arts in Applied Sciences in Warsaw	1	1	0	2
University of Zielona Góra	1	0	2	3
Warsaw University of Technology	1	1	0	2
Wrocław University of Technology	1	3	1	5
Entities employing 1 person	8	4	12	24
Sum	18	37	46	101

Source: own study based on data (People of Science Portal).

The scientific specialty in occupational safety and health or related specialties was declared by 101 persons with at least a doctoral degree and current employment as their primary place of work:

- persons with the academic title of professor (18, 17.8% share), including 18 entities of 1 person each.
- persons with the academic degree of habilitated doctor (37, 36.6% share), including at least 2 people: Central Institute for Labour Protection – National Research Institute (5), Poznań University of Technology (4), Silesian University of Technology (4), Central Mining Institute – National Research Institute (3), Wrocław University of Technology (3), Jagiellonian University in Kraków (2), Poznań University of Life Sciences (2), University of Bielsko-Biala (2), University of Agriculture in Krakow (2).
- people with a doctoral degree (46, 45.6% share), including at least 2 people: Silesian University of Technology (11), Central Institute for Labour Protection – National Research Institute (4), Poznań University of Technology (4), Częstochowa University of Technology (3), Lodz University of Technology (3), Central Mining Institute – National Research Institute (2), KOMAG Institute of Mining Technology (2), University of Zielona Góra (2).

The largest number of people declaring scientific specialty in occupational safety and health or related specialties was identified in the following entities (total number of people and number of independent scientists): Silesian University of Technology (16 and 5), Central Institute for Labour Protection – National Research Institute (9 and 5), Poznań University of Technology (8 and 4), Central Mining Institute – National Research Institute (6 and 4), Wrocław University of Technology (5 and 4), Częstochowa University of Technology (4 and 1), Lodz University of Technology (4 and 1).

Among the population of people declaring scientific specialty in occupational safety and health or related specialties, 10 people did not declare any discipline, and the remaining 91 people declared 17 disciplines (number of people), the dominant disciplines are management and quality sciences (34) and environmental engineering, mining and energy (33), other disciplines include: mechanical engineering (14), health sciences (6), forestry sciences (5), safety engineering (4), safety sciences (4), architecture and urban planning (3), psychology (3).

The population of people declaring scientific specialty in occupational safety and health or related specialties demonstrate an association with the obtained scientific degrees in the field of occupational safety and health (51, 50.5% share), including: doctor (27, 26.7% share), habilitated doctor (18, 17.8% share), and both doctor and habilitated doctor (6, 6.0% share).

The largest number of people declaring scientific specialty in occupational safety and health or related specialties was obtained academic degrees in the following entities (number of people): Silesian University of Technology (14), Central Mining Institute – National Research Institute (7), Lodz University of Technology (4), Poznań University of Technology (4), Wrocław University of Technology (4), Częstochowa University of Technology (3). 6 people hold both doctor and habilitated doctor: Grodzicka Aneta, Korban Zygmunt, Krause Marcin, Krzemień Alicja, Rypicz Łukasz, Skubacz Krystian.

3.4. Synthetic assessment of occupational safety and health

In the available literature, no research results were identified in the field of occupational safety and health analysis in the aspect of the discipline of safety engineering (apart from the author's publications presented in the introduction).

Based on own research (Krause, 2023, 2024d), the context of safety engineering or related disciplines and the criteria for the synthetic assessment of occupational safety and health in the aspect of the discipline of safety engineering or related disciplines were proposed for the analysis of occupational safety and health in the aspect of areas of science and education.

The proposal for the analysis of occupational safety and health in the aspect of areas of science and education includes the following disciplines:

- Safety engineering as the leading discipline.
- Related disciplines including: 2 disciplines of the social sciences (safety sciences, management and quality sciences) and 3 disciplines of the engineering and technical sciences (environmental engineering, mining and energy, civil engineering, geodesy and transport, mechanical engineering).

The proposal for synthetic assessment of occupational safety and health in the aspect of the discipline of safety engineering or related disciplines includes the following criteria:

- Basic criteria as detailed assessment of entities and persons, e.g.: teaching activity (higher studies, postgraduate studies), academic qualifications (disciplines), scientific activity (disciplines), scientific staff (disciplines).
- Additional criteria as supplementary assessment of entities and persons, e.g.: scientific staff (declared scientific specialty, obtained academic degrees), organization of scientific conferences, scientific publishing house (from the list of the Ministry of Science and Higher Education), scientific journals (from the list of the Ministry of Science and Higher Education), research programs (national, international).

The list of selected entities conducting scientific and teaching activity in the field of occupational safety and health in the aspect of the discipline of safety engineering or related disciplines is presented in Tables 7 and 8.

Universities and scientific institutes conducting long-term scientific research or research and teaching activity in the field of occupational safety and health in the aspect of the discipline of safety engineering or related disciplines can be divided into the following groups of entities of the higher education and science system:

- Scientific institutes conducting long-term scientific research in the field of occupational safety and health, including: Central Institute for Labour Protection – National Research Institute, Central Mining Institute – National Research Institute, Nofer Institute of Occupational Medicine.
- Academic universities authorized to award academic degrees in the discipline of safety engineering, including Fire University and WSB University.
- Technical universities conducting long-term scientific research and teaching activity in the field of occupational safety and health (only entities employing at least 4 people declaring scientific specialty in occupational safety and health), including: Częstochowa University of Technology, Lodz University of Technology, Poznań University of Technology, Silesian University of Technology, Wrocław University of Technology.
- Other entities conducting long-term scientific and teaching activity in the field of occupational safety and health, including: universities conducting higher studies in the field of study in occupational safety and health, safety engineering, other fields of study or postgraduate studies dedicated to the occupational safety and health service: other technical universities (np.: AGH University of Krakow, Cracow University of

Technology, Kielce University of Technology, Lublin University of Technology, Opole University of Technology, West Pomeranian University of Technology in Szczecin), public universities (np.: Casimir Pulaski Radom University, Jan Długosz University in Częstochowa, Kazimierz Wielki University, Medical University of Gdańsk, Medical University of Silesia in Katowice, University of Life Sciences in Lublin, University of the National Education Commission, University of Zielona Góra, Wrocław University of Environmental and Life Sciences), private universities (np.: Higher Engineering School of Safety and Labor Organization in Radom, Humanitas University in Sosnowiec, Private College of Environmental Protection in Radom, University of Occupational Safety Management in Katowice, WSB Merito University in Gdansk).

Table 7.

List of selected entities conducting scientific and teaching activity in the field of occupational safety and health in the aspect of the discipline of safety engineering or related disciplines (teaching activity, scientific activity, academic qualifications)

Name of entity	Teaching activity (higher study, postgraduate study)	Scientific activity (discipline)	Academic qualifications (discipline)
Central Institute for Labour Protection – National Research Institute	higher study (not applicable), postgraduate study (BHP)	IŚGiE	IŚGiE
Central Mining Institute – National Research Institute	higher study (not applicable), postgraduate study (none)	NoZiJ, IŚGiE, IM	IŚGiE
Częstochowa University of Technology	higher study (BHP), postgraduate study (none)	NoB, NoZiJ, IŚGiE, ILGiT, IM	NoZiJ, IŚGiE, ILGiT, IM
Fire University	higher study (BHP), postgraduate study (BHP)	IB, NoB, NoZiJ, IŚGiE, IM	IB, NoB, IŚGiE
Lodz University of Technology	higher study (IB); postgraduate study (BHP)	NoZiJ, IŚGiE, ILGiT, IM, NoZd	NoZiJ, ILGiT, IM
Nofer Institute of Occupational Medicine	higher study (not applicable), postgraduate study (none)	NoZd	NoZd
Poznań University of Technology	higher study (IB), postgraduate study (BHP)	IB, NoB, NoZiJ, IŚGiE, ILGiT, IM	NoZiJ, IŚGiE, ILGiT, IM
Silesian University of Technology	higher study (IB), postgraduate study (BHP)	IB, NoB, NoZiJ, IŚGiE, ILGiT, IM	NoZiJ, IŚGiE, ILGiT, IM
Wrocław University of Technology	higher study (BHP), postgraduate study (BHP)	NoZiJ, IŚGiE, ILGiT, IM	NoZiJ, IŚGiE, ILGiT, IM
WSB University	higher study (other fields in the scope of specialty BHP), postgraduate study (BHP)	IB, NoB, NoZiJ, IŚGiE, ILGiT, NoZd	IB, NoB, NoZiJ, ILGiT

Marks (PL): BHP – occupational safety and health, IB – safety engineering, ILGiT – civil engineering, geodesy and transport, IM – mechanical engineering, IŚGiE – environmental engineering, mining and energy, NoB – safety sciences, NoZd – health sciences, NoZiJ – management and quality sciences.

Source: own study based on data (RAD-on System, Disciplines...; RAD-on System, Bodies...; Council for Scientific Excellence, Powers...).

Table 8.

List of selected entities conducting scientific and teaching activity in the field of occupational safety and health in the aspect of the discipline of safety engineering or related disciplines (number of scientific staff – scientific discipline and scientific specialty)

Name of entity	Safety engineering and related disciplines (number of people)	Scientific specialty (number of people) / scientific discipline (number of people)
Central Institute for Labour Protection – National Research Institute	IB (1), NoZiJ (4), IŚGiE (136), IM (3)	BHP (9) / IB (1), NoZiJ (1), IŚGiE (9), NoZd (2)
Central Mining Institute – National Research Institute	NoZiJ (3), IŚGiE (235), IM (1)	BHP (6) / IŚGiE (6)
Częstochowa University of Technology	IB (4), NoB (10), NoZiJ (160), IŚGiE (67), ILGiT (51), IM (91)	BHP (4) / NoZiJ (4), IŚGiE (1)
Fire University	IB (37), NoB (37), NoZiJ (1), IŚGiE (54), ILGiT (1), IM (2)	BHP (0)
Lodz University of Technology	NoZiJ (83), IŚGiE (5), ILGiT (64), IM (126)	BHP (4) / NoZiJ (3), ITiT (1)
Nofer Institute of Occupational Medicine	NoZd (69)	BHP (2) / NoZd (2)
Poznań University of Technology	IB (2), NoB (7), NoZiJ (110), IŚGiE (103), ILGiT (183), IM (192)	BHP (8) / IB (1), NoB (2), NoZiJ (7), IŚGiE (1), IM (1), brak (1)
Silesian University of Technology	IB (3), NoB (4), NoZiJ (132), IŚGiE (251), ILGiT (199), IM (166)	BHP (16) / IB (1), NoB (1), NoZiJ (6), IŚGiE (8), IM (3), IMa (1), AiU (1)
Wrocław University of Technology	IB (2), NoZiJ (90), IŚGiE (275), ILGiT (153), IM (280)	BHP (5) / NoZiJ (3), IŚGiE (1), AiU (1)
WSB University	IB (17), NoB (23), NoZiJ (69), IŚGiE (3), ILGiT (17), IM (8)	BHP (0)

Marks (PL): AiU – architecture and urban planning, BHP – occupational safety and health, IB – safety engineering, ILGiT – civil engineering, geodesy and transport, IM – mechanical engineering, IMa – materials engineering, IŚGiE – environmental engineering, mining and energy, ITiT – information and communication technology, NoB – safety sciences, NoZd – health sciences, NoZiJ – management and quality sciences.

Source: own study based on data (RAD-on System, Disciplines...; RAD-on System, Academic...; People of Science Portal).

The presented example and the proposed criteria for synthetic assessment of occupational safety and health are pilot studies and will be the subject of subsequent publications.

4. Summary and conclusions

The scope of the publication covers, in turn: occupational safety and health as an area of knowledge, occupational safety and health as an area of education, occupational safety and health as an area of science, synthetic assessment of occupational safety and health in the aspect of the discipline of safety engineering or related disciplines.

The proposal for synthetic assessment of occupational safety and health in the aspect of the discipline of safety engineering or related disciplines includes, among others, the following groups of criteria: basic criteria (detailed assessment of entities and persons), e.g.: teaching

activity (higher studies, postgraduate studies), academic qualifications (disciplines), scientific activity (disciplines), scientific staff (disciplines); additional criteria (supplementary assessment of entities and persons), e.g.: scientific staff (declared scientific specialty, obtained academic degrees), organization of scientific conferences, scientific publishing house and scientific journals (from the list of the Ministry of Science and Higher Education), research programs (national, international).

Occupational safety and health in the aspect of the discipline of safety engineering or related disciplines is created by, among others, the following groups of entities of the higher education and science system: scientific institutes conducting long-term scientific research in the field of occupational safety and health (e.g.: Central Institute for Labour Protection – National Research Institute, Central Mining Institute – National Research Institute, Nofer Institute of Occupational Medicine), academic universities authorized to award academic degrees in the discipline of safety engineering (e.g. Fire University and WSB University), technical universities conducting long-term scientific research and teaching activity in the field of occupational safety and health (e.g.: Częstochowa University of Technology, Lodz University of Technology, Poznań University of Technology, Silesian University of Technology, Wrocław University of Technology), other entities conducting long-term scientific and teaching activity in the field of occupational safety and health, including universities conducting higher and postgraduate studies dedicated to employees of the occupational safety and health service.

Based on the conducted research and analyses, as well as the author's many years of scientific and teaching experience in this field, the following conclusions were formulated:

- Occupational safety and health as an area of scientific cognition can be considered in the aspect of the area of knowledge (chapter 3.1), the area of education (chapter 3.2) and the area of science (chapter 3.3), as well as developing an example and proposal of criteria for the synthetic evaluation of entities of the higher education and science system (chapter 3.4).
- The context of safety engineering as a new scientific discipline in the field of engineering and technical sciences creates opportunities for the development of occupational safety and health in the areas of science and education in the higher education and science system.
- The opportunities for the development of occupational safety and health as a specialty accepted by the academic community include the recognition of this area of science and education as an official scientific specialty in promotion procedures (doctor, doctor habilitated, professor).
- The population of people declaring a scientific specialty in occupational safety and health or related specialties is associated with the scientific degrees obtained in this field (51 out of 101 declared people), including: PhD (28 people), DSc (17 people), and both PhD and DSc (6 people).

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DIGITAL TOOLS IN THE PROCESS OF ARCHITECTURAL EDUCATION AS A METHOD OF STUDYING AND PROTECTING ARCHITECTURAL HERITAGE

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Purpose: The article presents the issue of the implementation and popularisation of the use of digital tools in practical classes focusing on the conservation of historic buildings for architecture students.

Design/methodology/approach: The study investigating the role of digital tools and the necessity of their implementation and expanded application in the field of architectural conservation education was conducted at the Faculty of Architecture of the Silesian University of Technology in Gliwice, as well as at selected technical universities in Poland and abroad. The research methodology included questionnaire-based surveys directed at architecture students and interviews with staff from the faculties.

Findings: The research indicates that the implementation of practical classes in the form of workshops is crucial, as it has a number of benefits. The implementation of such workshops provides an opportunity to develop and enrich the curriculum and encourage the student in conservation research and preservation of historical monument.

Research limitations/implications: Research conducted at higher education institutions in the Faculties of Architecture in Poland has shown that relatively few academic units include practical training in the use of digital tools as part of their curricula. Such courses are more commonly found in faculties that are integrated with civil engineering, where greater opportunities for collaboration and knowledge exchange exist. In contrast, the findings from foreign universities are more encouraging. Practical classes involving digital tools are conducted systematically and have yielded remarkable results throughout the didactic process.

Practical implications: The article may serve as a point of reference for the development of didactic strategies in architectural education and for determining the specific competencies and support students require in the course of architectural education.

Social implications: The benefits of young architects' ability to use digital tools influence their future perspectives in the profession. In addition, education in the use of these tools contributes to the preservation of architectural heritage, which is a common cultural good.

Originality/value: The article highlights the critical role of digital tools within architectural education, considering both the student and institutional perspectives. Manuscript fills the gap in the analysis of the use of digital tools in practical classes in the process of architectural education.

Keywords: digital tools, education, thermography, laser scanning, photogrammetry.

Category of the paper: Research paper.

Introduction

In the complex process of architectural education, the study of conservation and research of historic objects, particularly in terms of practical skills in using digital tools, is sometimes marginalised. However, it is worth bearing in mind that, in addition to the traditional methods of examining historic structures, which include the study of bibliography, archival documentation (drawings, cartography, photographs etc.), conservation documentation or surveys, as well as in situ surveys, which should form the basis of the research, methods of surveying buildings using digital tools together with the conducting of thermal analysis are an extremely valuable completion.

Digital methods have become increasingly popular in recent decades, the tools have been improved, the measurements have become more precise and their possible applications continue to expand (Ćosović, Maksimović, 2022). These include among others laser scanning, photogrammetry and thermal imaging measurements. These surveys, for example laser scanning, help to measure an object with much greater accuracy than traditional methods and record more data in less time (Karatzas et al., 2024). Moreover, thanks to the use of drones, it is possible to carry out these surveys in places where access is difficult or impossible. Digital tools provide valuable information about buildings that is impossible to examine without their use - they help determine the structure of a building, the layers that have formed over time, cavities, the technical condition of the building partitions, its humidity, etc. In addition, their remarkable value lies in the fact that they are non-invasive, non-destructive methods - so there is no concern that the research may negatively affect the surveyed heritage site.

Additionally, digital tools can be used to digitise heritage, which is considered one of the effective forms of heritage protection - to create so-called digital twins. The research carried out can be highly valuable for protecting the existing historic fabric, creating conservation guidelines, forecasting how the site will change, depending on external factors, or finally for developing design guidelines and making changes to the site to adapt it to changing user needs, comfort of use or energy efficiency (Bevilacqua et al., 2016). The popularisation of heritage also plays an important role in its conservation - including for example sharing electronic form of the object - digital models of historic buildings. Carrying out heritage surveys using digital methods therefore has not only scientific, documentation and application objectives, but also educational and popularisation purposes.

While it is common during architectural studies for students to be introduced to the theoretical knowledge of the digital tools in question, it is crucial to introduce practical workshops that will allow them to get a thorough understanding of the site and prepare conservation and design guidelines appropriately. The result of these workshops will at a later stage influence the practice and quality of the architectural profession and directly contribute

to the preservation of our heritage. According to research on universities in Poland and selected foreign universities, e.g. in Italy and Slovakia, so far very few faculties of architecture in Poland offer practical workshops in this field, and those are usually combined faculties of civil engineering and architecture. At foreign faculties combining civil engineering and architecture, practical classes have often been implemented as a permanent part of the curriculum, which has a huge impact on the future work of students studying there.

The article is aimed at presenting the possibilities and benefits of using digital tools in architectural education by introducing practical classes in the form of workshops. The article presents a methodology for surveying historic buildings using selected digital tools. Example results of the survey are presented and the possibilities of their application in design and conservation are highlighted. Additionally, the results of a survey are discussed, which shows how architecture students perceive the use of digital tools in architectural studies in the context of education and their motivation to use these tools in their design work.

Methodology of surveying historic buildings using selected digital tools and examples of results

New survey techniques are being successfully used in the study of historic buildings (Więcek, Poksińska, 2006). By digitisation activities in the area of monuments, we understand non-invasive measurement methods that are used for, among other things, inventory purposes (Czajkowski 2023) and thermal and humidity analysis. Performing a digital survey makes it possible to create a digital copy of an object and to analyse its historical-architectural features by cataloguing its losses, deformations, geometry and state of preservation. Precise dimensioning gives us the shape, structure of the three-dimensional surface, and colour not only of the external form, but also of the building's furnishings. Familiarising students with non-invasive digital methods, together with practical instruction on how to carry out research using the tools, will enable them to understand the whole process of conservation and conservation design of an existing monument. The aim of such classes would additionally be to create a copy of the monument reflecting and evaluating its technical condition with further knowledge of how to create as-built documentation. The materials created as a result of the activities will contribute to the creation of a database of information about the heritage site for research and educational purposes, as well as for the promotion of cultural heritage.

Photogrammetry and laser scanning

The photogrammetric method is an essential tool for the development and execution of architectural and building inventories. It is a branch of technical science that aims to characterise an object by taking photographs using ground-based as well as aerial techniques.

Through the use of digital cameras and survey cameras, photogrammetric images are taken, which make it possible to reconstruct the shapes, sizes and relative positions of objects in the site. The registration of images can take place in sites that are difficult to access and the fast registration of images with a large number of points makes it possible to collect a lot of important and reliable data about the site. A photogrammetric image is a true reflection of the object (Figure 1). However, there may be radial deviations due to the tilt of the image (Orłowski, Tunkiel, 2022).

Laser scanning is a technology that uses a laser to obtain an accurate measurement of distance. The point cloud that is obtained as a result of the inventory is an image of reality represented by a dataset of millions of measurement points (Figure 2). The process of laser scanning begins by setting up the scanner and emitting light rays which, after reflecting off the object, return to the scanner. By measuring the interval from when the ray is emitted to when it returns, the scanner calculates the distance to each point of the object. By repeating the process millions of times, a so-called point cloud is created, which is an accurate representation of the scanned object, making it possible to create a three-dimensional model of the monument being measured. “Laser scanning, in correlation with terrestrial digital photogrammetry, in a way that is above all extremely fast and non-interfering with the object, allows a very large amount of spatial data to be collected, with which a precise simulation of the object or part of it can be made” (Orłowski, Tunkiel, 2022).



Figure 1. Photogrammetry of historic Pavilion Wrzos in Goczałkowice Zdrój.

Source: Wałek, Krause- Świerczyńska.

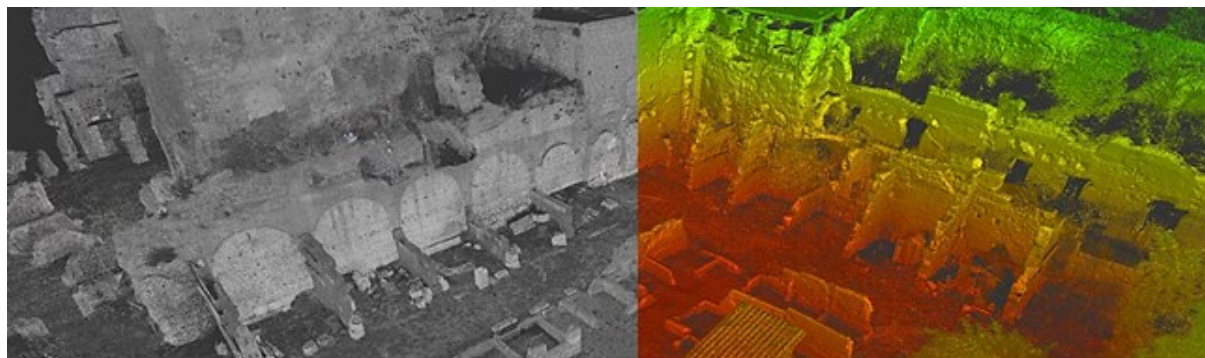


Figure 2. Laser scanning of Horrea Agripiana Rome.

Source: Wałek.

Thermal imaging surveys

Thermal imaging is a field of technology that deals with the detection, registration and imaging of infrared radiation emitted from the surface of the object under examination (Szmolke, 2015). It is an effective research tool that assists in evaluating the technical condition in terms of the thermal insulation of the building under examination. During thermal imaging surveys, the instantaneous temperature distribution on the surface of the building structure is recorded (Figure 3). A complete analysis of the thermal and humidity condition reveals the extent to which any defects exist and the regularity of the temperature distribution (Steidl, Krause, 2009). This analysis is carried out by comparing the measured temperature (thermogram) with the temperature calculated by numerical methods using appropriate computer programmes. Elements of a building diagnosed with a thermal imaging camera make it possible to determine the occurrence of humidity in external walls, infiltration of external air through partitions, the difference in thermal insulation of materials in a building partitions, as well as to check the thermal and humidity condition of selected fragments in terms of surface condensation using the fRsi index (Figure 4).

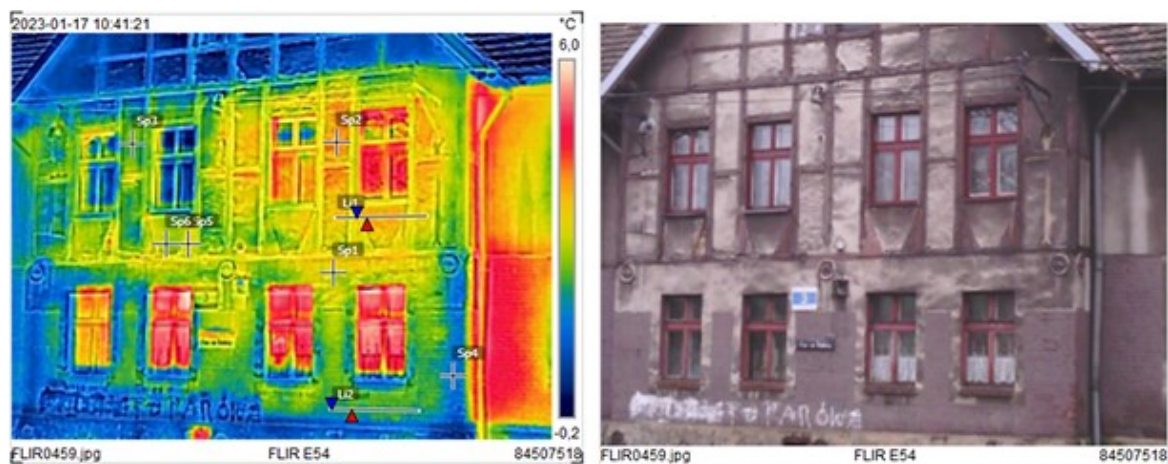


Figure 3. Thermal imaging surveys of building facades, Bytom, Osiedle Bobrek.

Source: Krause-Świerczyńska.

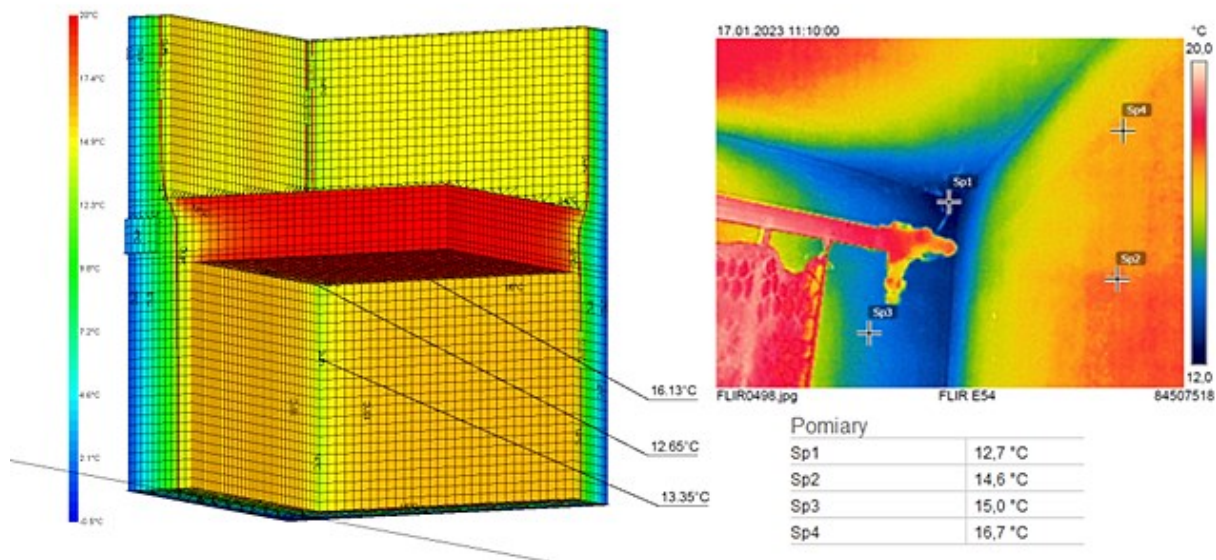


Figure 4. Thermal analysis of a selected detail in a 3D analysis program, Bytom, Osiedle Bobrek.
Source: Steidl.

Methodology Experience with practical classes on the use of digital tools in architectural education in Poland and abroad

The research shows that in Poland very few Faculties of Architecture introduce practical classes in the use of digital tools into the study programme. Much more often such classes take place at faculties that are combined with civic engineering. For the purposes of this article, the curriculum of the most important faculties of architecture in Poland and a few selected ones in Europe was analysed. Among those surveyed in Poland, only a few faculties offer practical classes in digital tools - usually in photogrammetry, less often in laser scanning. The surveyed universities do not offer thermal imaging studies at the faculties of architecture. At the Faculty of Architecture of the Silesian University of Technology, practical classes in photogrammetry, amounting to approximately 15 hours in the course Computer-aided Design, were piloted by PhD Eng Arch. Magdalena Walek, for part of the 2nd year of the 1st degree programme. In a similar number of hours at the Faculty of Architecture at the West Pomeranian University of Technology in Szczecin, students in the course Computer CAD Design have the opportunity to learn how to use laser scanners, on the example of scanning large spaces and small forms. An interesting form of conducting such classes is the introduction of digital tools within the scope of inventory practice - the examples of the Faculty of Architecture at Poznan University of Technology, the Faculty of Architecture of the Opole University of Technology, as well as the Faculty of Civil Engineering and Architecture of Kielce University of Technology, where within the scope of a two-week inventory practice, students learn surveying practices involving measurements of the object by digital photogrammetry and laser scanning. The case is different

abroad, where such classes are more common. For example, architecture students at the Department of Civil and Mechanical Engineering at the University of Cassino and Southern Lazio (UNICAS) and the Department of Humanities and Philosophy at UNICAS, have practical classes in laser scanning as well as photogrammetry with 10 hours of practise alone. According to the course instructors, Cassino students emphasise the extraordinary value of the practical classes and the fact that, thanks to their integration into the study programme, they can be recruited for important positions where the use of digital technologies is fundamental to their work. However, conducting workshops can be challenging. Course instructors emphasise the very small number of hours allocated to practical training, which means that the matters taught have to be reduced to the basics. Far more often than in practical workshops, students are confronted only theoretically with the topic of digital tools and their possibilities. However, of the largest faculties or institutes at technical universities offering a degree in architecture that have not yet introduced practical classes on the use of discussed digital tools, many units are planning to introduce more practical classes into the curriculum in the coming years.

Student's perspective on the issue of application of research results in the conservation and design process – results of survey

In order to study students' understanding of the use of digital tools in the conservation process, such as photogrammetry, scanning or thermal imaging research in the study of historic buildings, a survey was conducted among 56 master's students of the Faculty of Architecture at the Silesian University of Technology. The students taking part in the survey were enrolled in a course on conservation design in the academic year 2024/2025. As part of the course, students have lectures on conservation design, during which the theoretical aspects of researching historic buildings, including using modern digital tools, are covered. However, there are no workshops on the practical use of these tools, which in the opinion of the authors of the article and the students interviewed would be a valuable addition to architectural education.

Respondents were asked nine questions about the use of digital tools in architecture education. The first question concerned familiarity with research using digital tools in general. The question of whether the surveyee have had the opportunity to survey historic buildings using digital tools in your architectural education process was answered in the affirmative by only 17.9% of the respondents. The next questions focused on the specific digital tools discussed in the article - thermal imaging, photogrammetry and laser scanning. The largest percentage of respondents have had experience with laser scanning during their architectural education or design practice, with 35.7 % answering the question in the affirmative. 21.4 % of respondents had experience with thermal imaging, while the fewest (8.9 %) had used or made use of photogrammetry. The vast majority of second-level students surveyed had never had any

experience with building surveys using digital tools. Furthermore, the research showed that the vast majority of the students surveyed would like to have knowledge in this area. More than 96% indicated that incorporating digital tools into architectural education, in their opinion, would be useful, and more than 98% of respondents believe that having the knowledge and skills to use digital tools in the survey of historic buildings could positively impact their future employability. Interestingly, just less than 52% felt that this skill was necessary when working with a building structure. Respondents were also asked if they would be interested in learning how to use digital tools - over 98% answered in the affirmative.

Table 1 shows results of a survey on digital tools in architectural education.

Table 1.

Results of a survey on digital tools in architectural education

Survey question	Yes	No	No opinion
In your architectural education process, have you had the opportunity to study historic buildings using digital tools?	17,9%	82,1%	-
Have you had any experience with thermal imaging in your studies or work?	21,4%	78,6%	-
Have you had any experience with photogrammetry in your studies or work?	8,9%	91,1%	-
Have you had any experience with laser scanning in your studies or work?	35,7%	64,3%	-
In your opinion, would the introduction of digital tools into the architectural education process be useful?	96,4%	3,6%	-
In your opinion, could having the knowledge and skills to use digital tools in the survey of historic buildings have a positive impact on employment opportunities?	98,2%	1,8%	-
Is the ability to use digital tools necessary when working with a building structure?	51,8%	48,2%	-
Would you be interested in learning to use digital tools?	98,2%	1,8%	-
Do you find digital tools helpful in the design process?	92,8%	1,8%	5,4 %

Source: own study.

The analysis of the last open-ended question, concerning the usefulness of digital tools in the design process, resulted in interesting findings. Students most frequently indicated that digital tools:

- improve the surveying process, obtain more accurate information, improve the pre-design process,
- significantly reduce the margin for error, making the documentation of the building more reliable,
- allow for quick and precise building surveys,
- speed up work and simplify the design process,
- gives a better understanding of the subject matter - site, building, etc.,
- improve studying and modelling of buildings, especially those with little or no documentation,
- allows the collection of data that would be difficult or impossible to investigate without digital tools,
- help with digitalisation and documentation.

The results of the survey highlight both the students' awareness of the importance of using digital tools in the architectural profession and the need to introduce practical exercises in the use of digital tools into the process of architectural education.

Conclusion

The use of digital tools is an integral part of the conservation process. Thanks to the available advanced technologies, it is possible to support conservation efforts by creating detailed documentation. The ability to use digital tools and read the obtained results contributes to the preservation of cultural heritage, which is so important for future generations.

The use of thermal imaging in the examination of historic buildings, as a non-destructive diagnostic tool in conservation issues (Więcek et al., 2010), allows the identification and adoption of appropriate design solutions, such as the determination of the physical and chemical properties of the materials used, identification of brick threads under plaster, detection of brickworks, and, thanks to scanning technology and photogrammetry, it is possible to create precise digital models of the original buildings. Digital tools such as laser scanning, photogrammetry, thermal imaging or humidity measurements are non-destructive methods of surveying historical building. They are an excellent source of information for the precise identification of a building, its structure and its technical condition.

To support the effective integration of digital tools such as photogrammetry, laser scanning, and thermal imaging into curricula of architectural faculties, we propose a multi-layered approach. First, these technologies should be introduced gradually, beginning with theoretical modules that explain their principles and relevance to architectural practice. This foundation can be followed by practical workshops, ideally in the form of multiple in-situ research trips to heritage sites. In addition to subjects dedicated to digital tools we also recommend embedding using digital tool competencies into existing design studios and technical courses.

A meaningful integration of digital tools such as photogrammetry, laser scanning, and thermal imaging in architectural education faces several practical challenges. Among the most important are limited funding opportunities, which limit the ability of universities to invest not only in the necessary equipment and software, but also for in situ research trips for the groups of students that classes in heritage areas would entail. Additionally, there is often a shortage of adequately trained instructors who can confidently teach these technologies, as professional development in this area is still not widely prioritized among architects - It would therefore be advisable to provide staff with training or to have external experts teach such subjects. Addressing these barriers is essential to provide students with a practical experience with technologies that are increasingly relevant to contemporary architectural practice.

While digital tools such as photogrammetry, laser scanning, and thermal imaging offer immense value for heritage preservation, the discussion should also address the ethical and legal dimensions of their use. Questions of data ownership are particularly pressing—clarifying who holds the rights to 3D scans or other digital data about monument or heritage site is essential. Moreover, the lack of standardized protocols for digital archiving poses risks to long-term accessibility and reliability. Expanding the discourse to include these issues is vital to ensure that digital heritage practices remain responsible.

In conclusion – the research indicates that the implementation of practical classes in the form of workshops on the use of digital tools in the architectural education process is needed, as it has a number of benefits. Practical classes on the use of digital tools are extremely valuable and the implementation of such workshops provides an opportunity to develop and enrich the curriculum and encourage the student in conservation research and preservation of historical monument.

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ASSESSMENT OF INNOVATION AND ENVIRONMENTAL IMPACT OF A MANUFACTURING COMPANY IN THE CONSTRUCTION INDUSTRY

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Purpose: The aim of this article is to present an assessment of the innovativeness of a construction company using an original method of diagnosing the state of innovation.

Design/methodology/approach: The work uses an original method for diagnosing the state of innovation and eco-innovation of enterprises, enabling a comprehensive assessment of the level of innovation, identification of the main sources of environmental impact and analysis of the technologies used using the classification of technological readiness levels.

Findings: The company has an average level of innovation, with a clear advantage in terms of technological innovation. Currently, the company is not in the area of sustainable development. The LCA structure has shown that cement is the main source of the company's negative impact on the environment. The TRL (Technology Readiness Level) structure in the company is uneven and includes only level 8-9, which indicates the use of mainly externally acquired technologies. The obtained diagnosis of the company also allows for the indication of proposals for changes aimed at the company's development, which in the future will enable the achievement of sustainable development in terms of innovation and eco-innovation.

Research limitations/implications: In the future, the developed method can be used to conduct research in various industrial sectors, which will allow for the identification of specific challenges and opportunities in the field of innovation and eco-innovation in individual sectors of the economy.

Practical implications: The value of the article results from its practical nature – the developed method can be a support tool for enterprises in the process of planning development strategies, especially in the context of requirements related to ecological transformation and sustainable development.

Social implications: this method can contribute to improving the quality of social life - by supporting more sustainable construction practices, reducing the negative impact on the natural environment and promoting responsible attitudes in business. As a result, this translates into a healthier and safer living environment for current and future generations, thus supporting the goals of long-term socio-economic development.

Originality/value: The novelty presented in the article is the use of an original method of diagnosing the state of innovation and eco-innovation of an enterprise to assess the innovativeness of an enterprise from the construction industry, enabling a comprehensive assessment of not only the level of innovation, but also the identification of sources of environmental impact and the assessment of technologies used using the TRL classification.

It is a response to the existing research gap and can indicate possible directions of beneficial development changes for enterprises.

Keywords: innovations, eco-innovations, LCA, TRL.

Category of the paper: Research paper.

1. Introduction

Innovations, including eco-innovations, play a key role in economic development, contributing to both economic growth and increased competitiveness of countries, regions and enterprises. They can concern various areas of activity, such as: development of new or improved products and processes, implementation of modern technologies, improvements in logistics and distribution, organizational innovations and actions aimed at reducing the consumption of raw materials and energy.

The concept of innovation is interpreted in many ways, both in scientific literature and in business practice. It was first described in more detail by the Austrian economist Joseph A. Schumpeter in his work *Theory of Economic Development* from 1911. Schumpeter indicated innovations as an important factor of economic development (Schumpeter, 1960). The term "innovation" itself comes from the Latin *innovatio*, meaning the renewal or introduction of something new (Weir, 1994). According to the OECD and Eurostat definition, an innovation is a new or significantly improved product or process (or their combination) that differs significantly from previous solutions used by a given entity and that has been introduced to the market or implemented in an organization (OECD & Eurostat, 2018). Colloquially, innovation is most often identified with technical changes and understood as research and development activities conducted by economic entities, which result in inventions that are then introduced to the market" (Kalinowski, 2010; Wielewska, 2013).

The concept of eco-innovation was born in the 1990s as a response to the growing importance of innovation in the processes of economic development and the increasing problems related to the degradation of the natural environment. Like the concept of innovation itself, the term "eco-innovation" is multidimensional and is interpreted differently in the scientific literature. One of the first definitions of eco-innovation was proposed by C. Fussler and P. James in 1996. According to them, these are products and processes that not only reduce the negative impact on the environment, but also generate added value for both the company and the consumer (Fussler, James, 1996). Contemporary approaches to eco-innovation emphasize their complex nature and the variety of forms. Kemp and Pearson define eco-innovations as new methods of production, resource management, service provision or organizational activities for a given organization, which – analyzed throughout the entire life cycle of a product or service – contribute to the reduction of raw material consumption, pollutant emissions and negative impact on the environment (Kemp, Pearson, 2008). According

to the definition of the European Eco-Innovation Observatory (EIO), eco-innovation is the implementation of a new or significantly improved product, process, organizational change or marketing solution that results in a reduction of the consumption of natural resources and a reduction of harmful substance emissions throughout the product life cycle (EIO, 2013).

The common element of all definitions is the emphasis on achieving environmental benefits while maintaining or increasing the economic efficiency and competitiveness of the organization (Rybczewska-Błażejowska, 2019; Rybczewska-Błażejowska et al., 2022).

Assessing the ability of enterprises to implement innovative and eco-innovative solutions is a significant research challenge, mainly due to the ambiguity of these concepts and the diversity of methodological approaches used in research. The literature is dominated by general analyses covering innovations and eco-innovations at the national, regional and sectoral levels (European Commission, 2024). The results of these studies are used, among others, to develop competitiveness rankings that reflect the position of the surveyed entities on the local, national and global market. In-depth analyses of the innovation and eco-innovation of individual enterprises are published much less frequently. Additionally, there is still a noticeable lack of comprehensive methods enabling a comprehensive assessment of the innovation and eco-innovation of enterprises, which indicates the existence of a significant research gap in this area. This type of detailed research is necessary for a precise assessment of the real innovative and eco-innovative activity of enterprises, which plays a key role in their further development and adaptation to changing market conditions (Kaczmarska, 2015; Kumor-Sulerz et al., 2021).

The aim of this article is to present an assessment of the innovativeness of a construction company using an original method of diagnosing the state of innovativeness. This method offers a new perspective on the assessment of innovative activities, also taking into account the impact of products and technological processes on the environment. It is a response to the existing research gap and can indicate possible directions of beneficial development changes for companies.

In connection with the above, the analysis of the innovativeness and eco-innovativeness of a construction company, presented in the next chapter and based on the author's method of diagnosing the state of innovation, is of particular importance. It allows for a comprehensive assessment of the implemented technological solutions, taking into account their impact on the environment and the actions taken to reduce negative ecological effects. The construction industry, despite its traditional specificity, is increasingly becoming a space for the implementation of innovative and eco-innovative solutions (Czajkowska, Ingaldi, 2021, 2023; Kumor-Sulerz, Dziedzic-Jagocka, 2023).

2. Materials and methods

The method of assessing innovation and eco-innovation used in the study belongs to the group of detailed studies focusing on the analysis of individual enterprises. Within this method, innovation was assessed in two main functional areas:

- Technological innovation, including products, machines, devices and applied manufacturing technologies,
- Intellectual innovation, referring to creative, design, research and conceptual activities, the effect of which is the generation of knowledge and intangible resources.

The assessment of innovation is carried out according to a six-point scale (Kaczmarska, 2015, Kaczmarska, Gierulski, 2016). The assessment process also included the methodology of life cycle assessment - LCA (Life Cycle Assessment) and technology readiness level - TRL (Technology Readiness Level), which enabled the development of a detailed environmental profile of the enterprise. Thanks to this, it was possible to determine which elements of the activity - products, processes or other activities - are the main sources of environmental impacts (Rybaczewska-Błażejowska, Sulerz, 2017; Kumor-Sulerz, 2021; Kumor-Sulerz et al., 2021). The result of the study was not only a diagnosis of the current level of innovation of the company, but also an indication of possible directions of development that can contribute to increasing innovation efficiency and reducing the impact on the environment. This approach allows the company not only to better understand its own potential, but also to define strategies that increase its competitiveness and ability to implement innovations. In the conducted study of the company's innovation, various research methods were used, including both theoretical and empirical approaches, including analysis and criticism of the literature on the subject, statistical methods, observations, document analysis, interpretation of data from the studied entity. The basic technique for obtaining information was observation and direct interview with representatives of the management staff, conducted using an original questionnaire. This questionnaire covered issues related to technological and intellectual innovation, eco-innovation, as well as assessment of the level of technological readiness of the solutions used. In the part concerning eco-innovation, the interviews focused on the identification of products and related production processes and their impact on the environment. The collected data covered both input and output aspects of the analyzed processes - including the consumption of raw materials, materials and energy, emission of pollutants into the air, water and soil, as well as the amount of waste generated. In the context of assessing technological readiness, the interviews allowed for determining the company's potential in the field of developing and implementing new technologies - from the concept stage to the full implementation of new products and processes.

3. Case study

The case study presented below aims to comprehensively assess the innovativeness and eco-innovativeness of a company producing paving stones, curbs, edges and garden slabs using the method of diagnosing the state of innovativeness of companies. The company constantly strives to improve its organizational and management processes in order to effectively respond to the growing requirements of its customers. Attention to innovation and product quality means that the company not only maintains a high level of customer satisfaction, but also stands out from the competition. The company regularly monitors changes and new trends in the construction market, which allows it to introduce new solutions and expand its offer with the latest products. Thanks to the close combination of tradition and modernity, the company maintains its position as a leader in the industry in terms of the quality of manufactured products. It has implemented the ISO 9001:2000 Quality Management System, which is a guarantee of the highest standard of products and continuous improvement of production and management processes. Selected high-quality materials are used in production, such as aggregates, cement with increased strength parameters, dyes and other chemical additives obtained from proven suppliers, which ensures the stability and durability of the final products. The selection of materials for production is based on many years of experience and in-depth knowledge of the specifics of the industry. In addition, the company invests in modern production technologies, which allow obtaining products with excellent technical parameters, guaranteeing their longevity and reliability in use. The study was conducted in accordance with the stages presented in Figure 1.

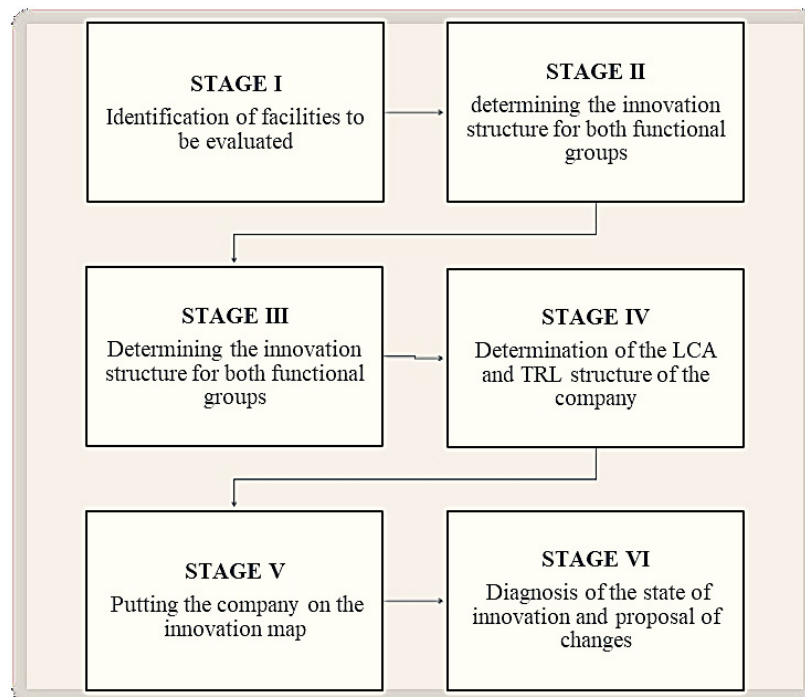


Figure 1. Stages of the methodology for the evaluation of the level of innovation of enterprises.

Source: (Kumor-Sulerz et al., 2021).

Stage 1 – identification of facilities to be evaluated. In the table below 1, the areas important in the conducted study, divided into both functional groups, are specified in the first stage. Technological innovation is activities directly related to products and the production process, including products, machines and devices, applied production techniques, production employees. Intellectual innovation is activities related to creative design, creative thinking, research and development work, i.e. activities that result in intangible products (Kumor-Sulerz, et al., 2021; Kumor-Sulerz, Michta, 2022).

Table 1.
Assessment of enterprise innovation

Enterprise			
Functional group	Scope of activity		
	Range	Evaluated factors	Rate
Technological innovation	Manufactured product	Quality requirements of manufactured products met Traditional materials used in production	$\beta_{5=0,1}$ $\beta_{3=0,1}$
	Manufacturing techniques	Automatic production lines Fulfillment of ecological requirements	$\beta_{5=0,1}$ $\beta_{4=0,1}$
Intellectual innovation	Research and development work	Monitoring the market development of innovative technologies Frequency of introducing innovative technologies	$\alpha_{3=0,1}$ $\alpha_{2=0,1}$
	Organization and management	Participation in fairs Promotion in the media	$\alpha_{4=0,1}$ $\alpha_{3=0,1}$

Source: Own research.

Stage 2 – determining the innovation structure for both functional groups.

In the enterprise, the innovation structure coefficients α_i and β_i were determined for both functional groups according to formulas (1), (2). The innovation structure of the enterprise is presented in Table 2 and Figure 2.

$$\alpha_i = \frac{u_i}{\sum_{i=1}^6 u_i} \cdot 100\% \quad (1)$$

$$\beta_i = \frac{v_i}{\sum_{i=1}^6 v_i} \cdot 100\% \quad (2)$$

where:

u_i – is the number of facilities belonging to the corresponding innovation zone i ($i = 1, \dots, 6$) in the area of intellectual innovation,

v_i – is the number of facilities belonging to the corresponding zone i ($i = 1, \dots, 6$) in the technological innovation area.

Table 2.
Enterprise innovation structure

	Innovation zone	Structure coefficients α of intellectual innovation		Structure coefficients β technological innovation	
Conservative (non-innovative)	Definitely	α_1	0,18	β_1	0,00
	Average	α_2	0,18	β_2	0,18
	Moderately	α_3	0,27	β_3	0,45
Innovative	Definitely	α_4	0,18	β_4	0,36
	Average	α_5	0,18	β_5	0,00
	Moderately	α_6	0,00	β_6	0,00

Source: Own research.

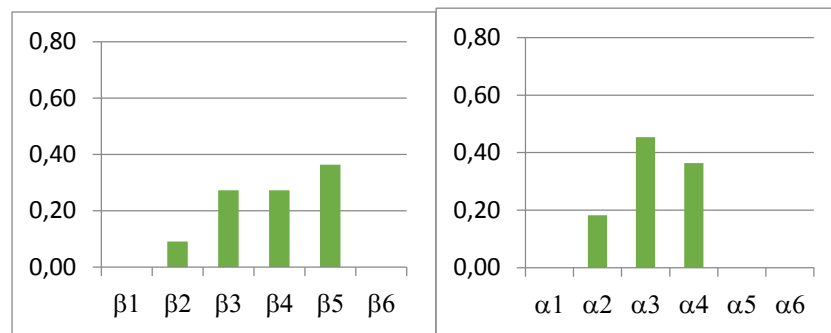


Figure 2. The structure of the company's innovation for both functional groups.

Source: Own research.

Stage 3 – determination of innovation indicators for both functional groups. During this stage, the values of the indicators of the structure of intellectual innovation (α_0) and technological innovation (β_0), are determined, based on which the values of intellectual innovation W_{IK} and technological innovation W_{IT} are determined, according to formulas (2) and (3) (Kaczmarzka, 2015, Kumor-Sulerz et al., 2021).

$$\alpha_0 = \frac{\sum_{i=1}^6 i \cdot (\alpha_i)}{\sum_{i=1}^6 (\alpha_i)} \quad (3)$$

$$\beta_0 = \frac{\sum_{i=1}^6 i \cdot (\beta_i)}{\sum_{i=1}^6 (\beta_i)} \quad (4)$$

$$W_{IK} = W_I \text{ dla } \mu_0 = \alpha_0 \quad (5)$$

$$W_{IT} = W_I \text{ dla } \mu_0 = \beta_0 \quad (6)$$

$$W_I = 0,10 \cdot \mu_0 - 0,10 \text{ dla } 1 \leq \mu_0 < 2$$

$$W_I = 0,15 \cdot \mu_0 - 0,20 \text{ dla } 2 \leq \mu_0 < 3$$

$$W_I = 0,50 \cdot \mu_0 - 1,25 \text{ dla } 3 \leq \mu_0 \leq 4$$

$$W_I = 0,15 \cdot \mu_0 + 0,15 \text{ dla } 4 < \mu_0 \leq 5$$

$$W_I = 0,10 \cdot \mu_0 + 0,40 \text{ dla } 5 < \mu_0 \leq 6$$

In the enterprise, the indicator values are:

$$W_{IT} = 0,77 \quad W_{IK} = 0,42$$

Stage 4 – determination of the LCA and TRL structure of the company.

Structure LCA

The aim of the study is to assess the environmental impact of the company in the context of its production activities. The scope of the LCA analysis includes identified products and production processes in the company, including the paving stone production line. The study used a functional unit of 1Mg (megagram) of the final product, which is a reference point for the inventory of input and output data in the production process. This made it possible to determine the environmental impact of each stage of paving stone production in relation to the amount of product produced. In the next stage of the study, the system boundaries were determined, which included all processes related to the production of paving stones. The system boundaries included all phases from the acquisition of raw materials to the production of the

finished product. Figure 3 shows the scope of the LCA analysis in the company, illustrating all key processes in the production of paving stones.

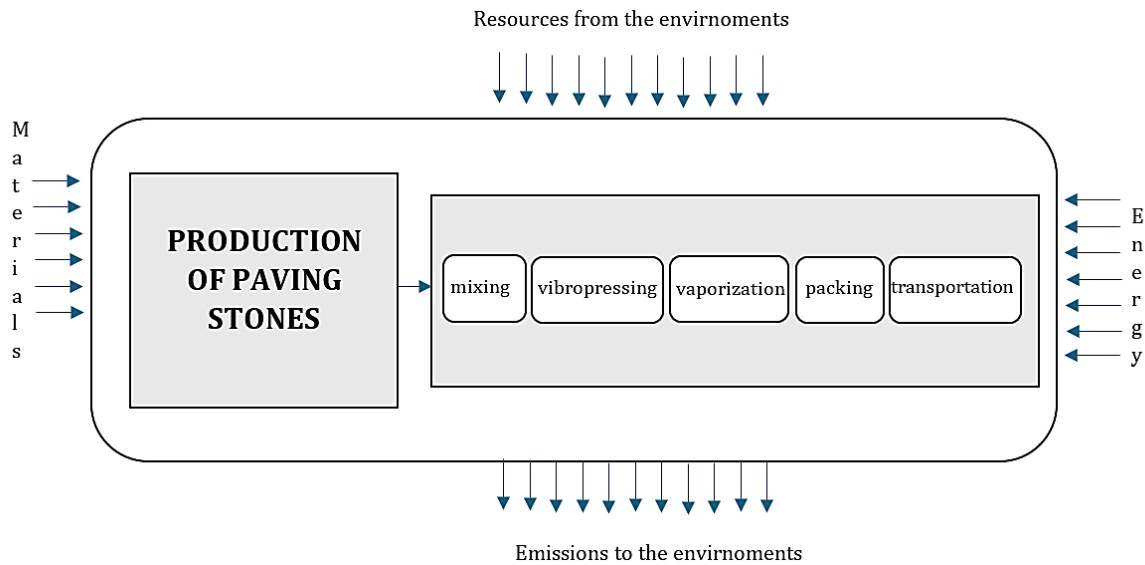


Figure 3. The area of life cycle analysis (LCA) and its basic unit processes.

Source: Own research.

Then, all input and output data related to production were collected. The inputs included materials, stones, water, and the outputs included emissions of pollutants into the air, soil, and water, as well as production waste. Based on the collected data, an environmental balance sheet of the company was created, which included detailed information on the impact of production activities on the environment. This balance sheet included:

- Materials used in the production stones.
- Energy and water consumption.
- Emissions of pollutants into the air, soil, and water.
- Generation of final waste.

The input and output data related to the production of paving stones are presented in Figure 4.

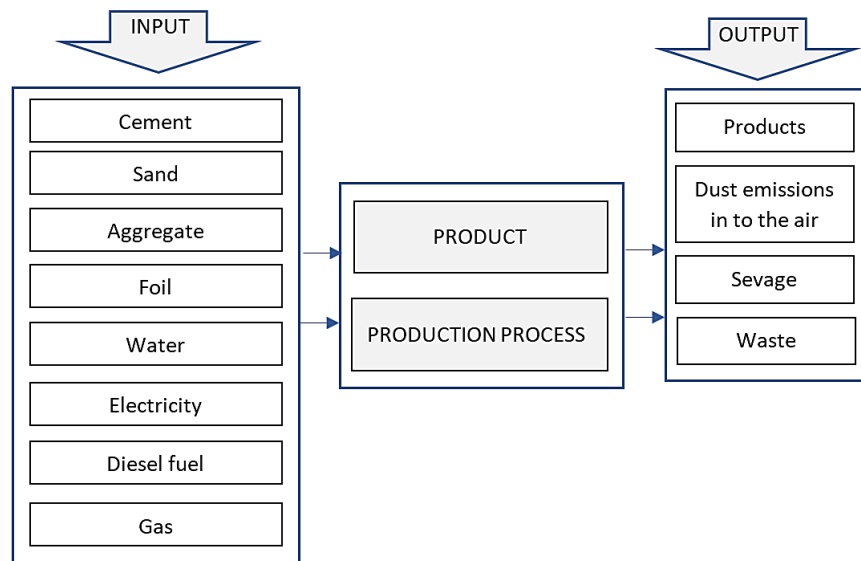


Figure 4. Input and output data related to paving stone production.

Source: Own research.

The LCIA of the company was performed using specialist software Sima Pro 8.1.1 and the ReCiPe Midpoint (H) method included with it. The next stage of the company assessment is to determine the company's environmental profile (LCA structure). This stage includes determining the matrix a_{ij} (MAT_{LCA}), which presents the environmental impact of individual products and production processes of the company ($i = 1, \dots, n$), expressed in impact category indicators ($j = 1, \dots, m$). The selection of the impact category depends on the selected LCIA method. The matrix recorded in this way (MAT_{LCA}) enables the determination of LCA structure factors α_n within individual impact categories (Kumor-Sulerz et al., 2021). The company's environmental profile in the form of a MAT_{LCA} table takes the form:

$$M_{TRL} = [0,0062 \ 0,0001 \ 0,0044 \ 0,0126 \ 0,0014 \ 0,0099 \ 0,0024 \ 0,0041 \ 0,0002 \ 0,0136 \ 0,0165 \ 0,0003 \ 0,0001 \ 0,0006 \ 0,0324 \ 0,0000 \ 0,0008 \ 0,0047]$$

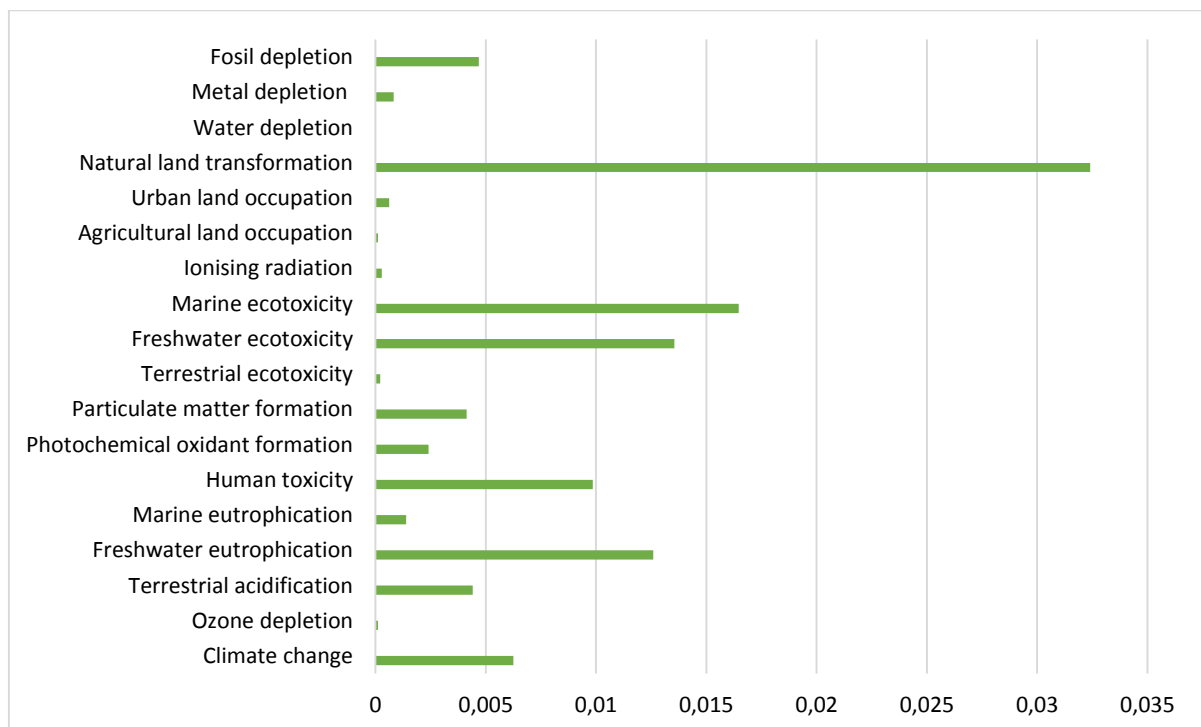
A row in the matrix refers to the product manufactured in the company and its associated production process, i.e. the production process of paving stones. The columns correspond to specific impact categories. According to the ReCiPe Midpoint (H) method, i.e.: climate change, ozone depletion, terrestrial acidification, freshwater eutrophication, marine eutrophication, human toxicity, photochemical oxidant formation, particulate matter formation, terrestrial ecotoxicity, freshwater ecotoxicity, marine ecotoxicity, ionising radiation, agricultural land occupation, urban land occupation, natural land transformation, water depletion, metal depletion, fossil depletion. The LCA structure factors are defined in Table 3.

Table 3.

Enterprise structure coefficients in individual impact categories in the ReCiPe Midpoint (H) method

	Production of paving stones	Structure factors $\alpha_i = \sum_{n=1}^j \alpha_{n1}$
Climate change	0,0062	0,0062
Ozone depletion	0,0001	0,0001
Terrestrial acidification	0,0044	0,0044
Freshwater eutrophication	0,0126	0,0126
Marine eutrophication	0,0014	0,0014
Human toxicity	0,0099	0,0099
Photochemical oxidant formation	0,0024	0,0024
Particulate matter formation	0,0041	0,0041
Terrestrial ecotoxicity	0,0002	0,0002
Freshwater ecotoxicity	0,0136	0,0136
Marine ecotoxicity	0,0165	0,0165
Ionising radiation	0,0003	0,0003
Agricultural land occupation	0,0001	0,0001
Urban land occupation	0,0006	0,0006
Natural land transformation	0,0324	0,0324
Water depletion	0,0000	0,0000
Metal depletion	0,0008	0,0008
Fossil depletion	0,0047	0,0047

Source: Own research.

**Figure 5.** Enterprise LCA structure.

Source: Own research.

The analysis of the LCA structure of the company indicates that it generates the greatest negative impacts on the environment in such impact categories of natural land transformation, marine and freshwater ecotoxicity, and freshwater eutrophication (Fig. 5). The LCA analysis shows that the materials used for the production of paving stones are the primary source of pollution in the company in all key impact categories. For example, cement is responsible for 97.9% of all impacts in the impact category of human toxicity (Fig. 6), and 83.9% of all impacts in the impact category of natural land transformation (Fig. 7).

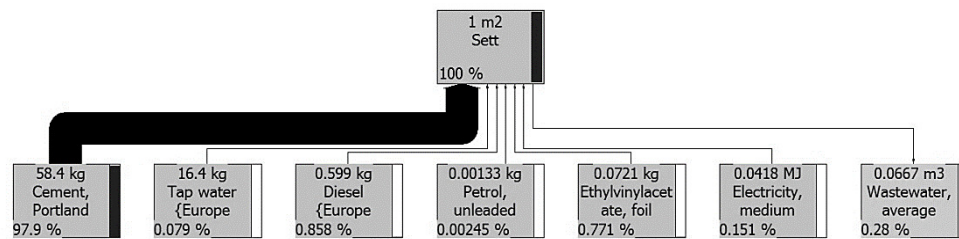


Figure 6. Paving stone production process tree in the category of human toxicity impact.

Source: Own research.

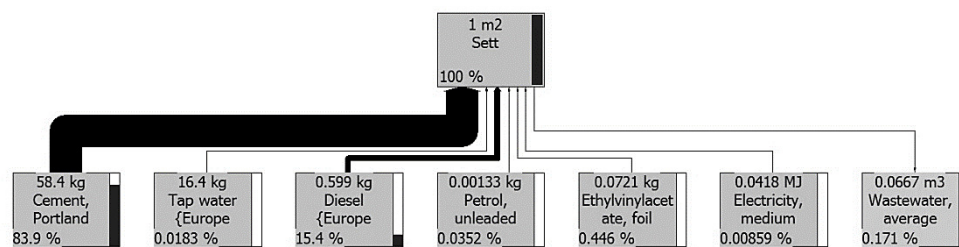


Figure 7. Tree of the paving stone production process in the impact category of natural land transformation.

Source: Own research.

TRL structure

After identifying the technologies used in the enterprise that may be subject to TRL classification, the TRL matrix is determined (M_{TRL}), where the columns correspond to the subsequent levels of technology readiness TRL, while the rows characterize the technologies implemented in the examined enterprise. Two technologies were identified in the enterprise that were subjected to TRL assessment. These technologies correspond to the subsequent rows of the matrix M_{TRL} (Kaczmarska et al., 2015; Kumor-Sulerz et al., 2021).

$$M_{TRL} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

Table. 4

The state of enterprise technology according to the TRL methodology

Enterprise	TRL 1	TRL 2	TRL 3	TRL 4	TRL 5	TRL 6	TRL 7	TRL 8	TRL 9
Technology 1	0	0	0	0	0	0	0	1	1
Technology 2	0	0	0	0	0	0	0	1	1

Source: Own research.

Technology 1 – concrete mixing. Producing concrete with the best possible properties is the basis for the production of paving stones. Properly selected ingredients and the use of modern technologies allow for obtaining high-quality products. Aggregates for production are obtained from nearby deposits. In the next stage, multi-grained sand is delivered to a container equipped with a scale, which is mixed with appropriately selected aggregate. Then the mixture is transported to a dumping container located on a rail ramp, which is moved to the inlet of a large mixer. Cement, water and dyes are added to the mixer through nozzles. The ready mixture is transported to a mold in which paving stone patterns are pressed. The work carried out in the company related to this technology is located in the range of TRL level 8-9 with an average degree of complexity. Level 8 – concrete mixing technology was carried out – suggested comments regarding the obtained concrete were taken into account. Level 9 – concrete mixing technology has been tested in operational conditions - with a positive result. The company has been using the described concrete mixing technology to date.

Technology 2 – vibro-pressing of concrete. Concrete is subjected to the vibro-pressing process, which uses a vibrating press of the German brand OMAG with a pressure of 10 tons, which compacts the ready mix. The purpose of concrete compaction is to remove the air inside the mold. This process lasts about 10 seconds, during which the mold is temporarily removed using hydraulic actuators, leaving the formed concrete on the plate. In the next stage, the plates are placed on a special frame and directed to a dryer, where the temperature is 38 C. The work carried out in the company related to this technology is located in the range of 8-9 TRL level with an average degree of complexity. Level 8 – the concrete vibro-pressing process was carried out and the suggested comments regarding the obtained concrete were taken into account. Level 9 – the technology was tested in operating conditions - obtaining a positive result. The company has been using the discussed concrete vibro-pressing technology to this day.

The TRL structure factor calculated according to the formula (7):

$$\vartheta_i = \frac{\sum_{k=1}^n a_{ik}}{\sum_{i=1}^9 \sum_{k=1}^n a_{ik}}, \text{ for } i = 1 \dots 9 \quad (7)$$

$$\vartheta_i = 0,02$$

The TRL index was calculated according to the formula (8):

$$W_{TRL} = \frac{\sum_{i=1}^9 i \cdot \vartheta_i}{\sum_{i=1}^9 \vartheta_i} \quad (8)$$

$$W_{TRL} = 8,5$$

The TRL structure of the company is presented in Figure 8.

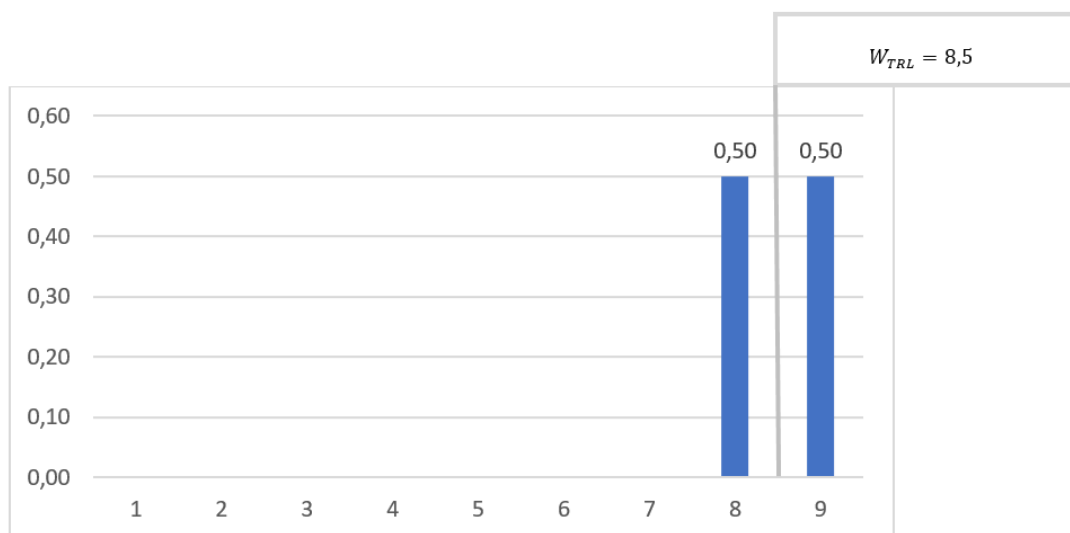


Figure 8. Company TRL structure.

Source: Own research.

Stage 5 – presentation of the company on the innovation map (see Fig. 6). The innovation map is a graphical presentation of indicators W_{IK} i W_{IT} designated for both functional groups. These indicators in the analyzed company are $W_{IT} = 0,77$ i $W_{IK} = 0,42$, which is shown in Figure 9.

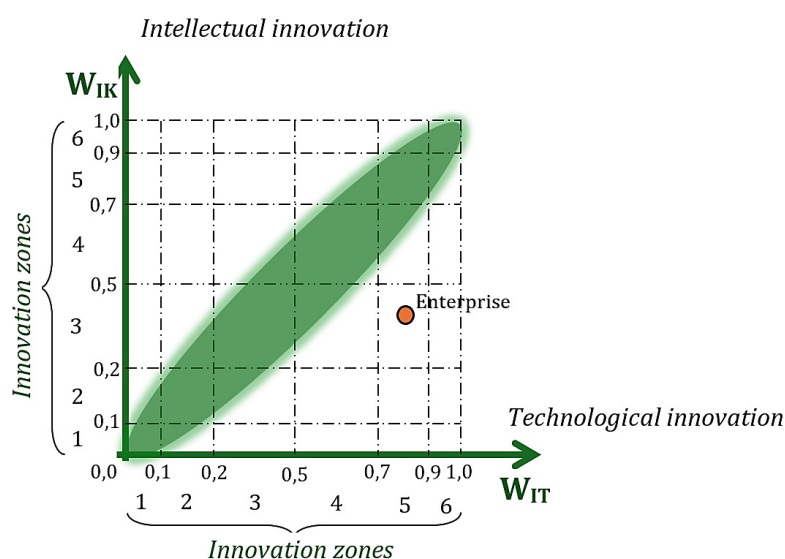


Figure 9. Enterprise Innovation Map.

Source: Own research based on (Kaczmarska, 2015).

Stage 6 – diagnosis of the state of innovation and proposal of changes. The location of the company on the innovation map allows to determine the state of the company's innovation, determines the recommended directions of changes, indicates the areas of activities in which rational decisions regarding improvements should be made and the areas constituting its strengths (Kumor-Sulierz et al., 2021).

The company has an average level of innovation, with a clear advantage in technological innovation. Currently, the company is not in the area of sustainable development. The suggested changes include initiating activities to ensure the development of intellectual innovation.

These activities will create the foundations for achieving sustainable development in the future. A key element in this process will be active cooperation with research and development centers, employee training or employment of highly qualified staff. Such activities will enable the company to create its own innovative technologies and implement them in production. The company's analysis conducted using the LCA method showed that products are the main source of negative impact on the environment, especially in categories such as transformation of natural areas, ecotoxicity (both marine and freshwater) and eutrophication of freshwater. The greatest environmental damage results from the use of cement in the production of paving stones. In order to reduce this impact, the company should focus on implementing eco-innovations in the area of products, including by reducing the consumption of materials such as cement and increasing the durability and strength of the raw materials used. At the material level, we can point to the use of alternative cement binders, such as geopolymers or fly ash, as well as the use of recycled materials and renewable and bio-inspired materials, such as industrial hemp or mycelium (mycelium). Such approaches help reduce the carbon footprint and reduce the impact on the natural environment. In the context of design processes, it would be important to take into account modern digital optimization methods, such as Building Information Modeling (BIM), generative design, or 3D printing using low-emission materials. At the same time, it is worth promoting design strategies based on modularity and the possibility of disassembling and reusing components, which favors the implementation of the principles of the circular economy. At the system level, references to design based on life cycle analysis (LCA), the implementation of circular economy assumptions and the use of environmental certifications, such as LEED or BREEAM, which are important tools supporting the strategy of sustainable development in construction, are important. At the material level, we can point to the use of alternative cement binders, such as geopolymers or fly ash, as well as the use of recycled materials and renewable and bio-inspired materials, such as industrial hemp or mycelium (mycelium). Such approaches help reduce the carbon footprint and reduce the impact on the natural environment. The structure of TRL (Technology Readiness Level) in the company is uneven and covers only the 8th-9th level, which indicates the use of mainly technologies acquired from outside. The $W_{TRL} = 8.50$ indicator is in the second part of the $W_{TRL} < 4.5$ range, which indicates limited research and development activity. In order to increase innovation capabilities, the company should focus on the development of research and development works and independent creation of new technologies. Active cooperation with research and development centers and the development of employee competences will allow for independence from technologies acquired from outside, as well as the creation of a strong R&D department. Hiring highly qualified employees would allow for the adaptation and development of technology in accordance with the company's needs, instead of relying solely on the purchase and implementation of ready-made solutions.

4. Conclusion

The article presents an assessment of the level of innovation and eco-innovation of a manufacturing company operating in the construction industry, using an original method of diagnosing the state of innovation. The innovative contribution of this article is the application of an original method for diagnosing innovativeness and eco-innovativeness of enterprises, which was used in the case study of a company from the construction sector. The advantage of the proposed approach is its comprehensiveness – it allows not only for the assessment of the general level of innovativeness, but also for the identification of the main areas of environmental impact and the assessment of applied technological solutions using the TRL (Technology Readiness Level) classification. The method of assessing innovation and eco-innovation used in the study is classified as a detailed study that focuses on the analysis of individual companies.

This method enabled a comprehensive analysis of the company through:

- assessment of the level of innovation and eco-innovation,
- identification of sources of environmental impact (product, production process),
- assessment of applied technologies according to the TRL (Technology Readiness Level) classification.

The company has an average level of innovation, with a clear advantage in terms of technological innovation. Currently, the company is not in the area of sustainable development. The LCA structure has shown that cement is the main source of the company's negative impact on the environment. The TRL (Technology Readiness Level) structure in the company is uneven and covers only level 8-9, which indicates the use of mainly externally acquired technologies. The obtained diagnosis of the company also allows for the indication of proposals for changes aimed at the development of the company, which in the future will enable the achievement of sustainable development in the aspect of innovation and eco-innovation. This method addresses a significant research gap regarding practical tools supporting the transformation of enterprises towards sustainable development. It can provide valuable support in the strategic planning process, indicating possible directions of changes at both the operational and technological level. At the same time, its application in a broader industry context requires further validation and adaptation to the specifics of individual sectors of the economy.

The method proposed in this paper contributes to the literature by combining the concepts of TRL and LCA, which allows for a comprehensive assessment of innovation and its impact on the environment. Thus, the interdisciplinary research framework linking technology management, ecology and sustainable development is strengthened.

The company's diagnosis reveals that although the company demonstrates an average level of innovation, it requires further improvement, especially in the context of the significant impact of cement production on the environment. The uneven structure of TRL levels, with the dominance of externally acquired technologies, indicates the need to invest in the development of own innovations and strengthen technological competences.

In practice, the method is a useful tool supporting companies in identifying weak points and development priorities, enabling planning of activities aimed at increasing innovation and achieving sustainable development goals. The proposed solutions, based on the diagnosis, can help the company reduce the negative impact on the environment, among others by searching for alternative materials or production technologies. The method can also act as a decision-making support in the field of innovation management and ecological transformation, which is particularly important in industries with a high environmental impact, such as construction.

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SELECTED CRITERIA FOR EVALUATING WORKING CONDITIONS – A CASE STUDY

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Purpose: The purpose of this article is to analyze the working conditions of university employees in the context of health, safety and ergonomics, with a particular focus on the challenges of computer work. In the face of dynamic technological changes, prolonged use of digital devices can negatively affect vision, musculoskeletal system and mental well-being. The survey was designed to identify areas for improvement and incorporate the perspective of employees in shaping the work environment.

Design/methodology/approach: The study was conducted using a questionnaire aimed at administrative, research and teaching staff at one of the universities. The questionnaire covered four key areas: work environment, technical equipment, ergonomics of the computer workstation and work organization. The collected data was analyzed quantitatively and qualitatively to identify strengths and problem areas.

Findings: Analysis of the results showed that while there are positive aspects of the work environment, there are also significant deficiencies in ergonomics, health and safety. Employees reported the need for better adjustment of workstations, especially in terms of ergonomics of computer equipment and more efficient organization of duties. Respondents' opinions provided valuable information that can form the basis for implementing specific improvements.

Research limitations/implications: The survey is limited to a single institution and is based on respondents' subjective evaluations. Further research could include a comparison between different universities and an expansion of the methodology to include job observation.

Practical implications: The results of the survey can be used as a basis for developing recommendations for improving working conditions, such as by implementing ergonomic solutions and systematically monitoring employee feedback.

Social implications: Improving the ergonomics and well-being of workers can positively affect their psychophysical health, work efficiency and overall quality of life.

Originality/value: The article brings new knowledge about academics' perceptions of their working conditions and highlights the value of their voices in improving the work environment.

Keywords: occupational health and safety, ergonomics, conditions of work, survey, employee.

Category of the paper: Research paper.

1. Introduction

The technical university employs its staff on various positions, ranging from administrative, scientific and technical. So the issues of safety, hygiene and ergonomics in their work environment are diverse. In addition to the analysis of selected aspects of the formation of conditions of work, the article emphasizes the link between the specificity of the work performed by employees of scientific and educational units and hardware. The research method applied involves a diagnostic survey method, and a survey addressed to the employees of a scientific and educational unit was applied as a research tool. The survey consists of several parts and is aimed at gathering the opinions and experiences of employees on aspects that shape conditions in their workplace. The survey was anonymous.

The research problem boils down to answering the following questions:

- Does the level of safety and ergonomics at a higher education institution include only the necessary recommendations, the so-called minimum health and safety requirements?
- Does the level of safety and ergonomics at the university meet staff expectations and needs?

The provision of safe and healthy conditions of work is a legal and social obligation of every employer, as well as an entrepreneur for which natural persons perform work, including those working under contracts of mandate and contract for specific work, as well as the self-employed, regardless of the basis on which this work is provided (The Labour Code Act, 1974). Occupational safety can be defined as the activity leading to the protection of the employee against accidents (or possible hazards) at work (Ejdasy et al., 2010). It is implemented through the application of various technical means, appropriate organization of work and formation of appropriate human behavior during work performance, taking into account the type and intensity of potential occupational hazards occurring (Hansen, 1998). Occupational health, on the other hand, deals with the effects on humans of various harmful factors (e.g. chemical, physical or biological) present in the working environment. According to the PWN Encyclopedia, one of the main aims of the “modern occupational health is to counteract mental fatigue and the one-sided effect of work on the human body, resulting, among other things, from the negative effects of the mechanization of production and the new nature of mental work” (Popularna Encyklopedia PWN, 2020). Apart from occupational health and safety, the matter of ergonomics is an equally important aspect in fulfilling the above obligation. The law requires the employer to design and adapt the workplace for both new and existing employees (Rączkowski, 2014). The fundamental aim of ergonomics is to humanize work through such functioning of the man-machine-environment system so that human work is performed as effectively as possible and at the lowest possible physiological cost, while preserving the physical and mental comfort of the employee. Organizing work at a work station

according to ergonomic as well as hygienic and safety requirements increases productivity and efficiency of employees (The Decree of the Minister..., 2003; Shobe, 2018; Wróblewska, 2004). Globally, such as in Korea, studies have been conducted on factors affecting satisfaction with working conditions, among others, which change over time, and found that interpersonal relationships and the social environment in the workplace play an increasingly important role (Lee, Park, 2021). In addition, a study from a Brazilian university found that improving working conditions can prevent psychological problems among workers, and that detailed analysis of their factors enables better prioritization of corrective actions (Borges et al., 2023). Changes in the work environment and the introduction of ergonomic interventions in workstations positively affect productivity, as demonstrated in a study of administrative staff at another university, highlighting the role of ergonomics and anxiety reduction in improving organizational effectiveness (Baleshzar, 2022).

2. Materials and methods – methodology

A diagnostic survey method was used in this study. An anonymous survey completed by 280 technical university staff in administrative, research, research and teaching positions was the research tool. The study was conducted (in March-April 2020) at the beginning of the pandemic during a period of many university operational constraints (Łochańska, 2020).

The research survey divided employees into four groups, three of which included academic positions, i.e. research, research and teaching (professors, university professors, assistant professors, assistants, senior lecturers, lecturers, senior instructors, instructors). The administrative staff in the survey is a group of employees not included in the above-mentioned groups, mainly employees from the administrative service of the university and employees supporting the scientific and teaching group, i.e. engineering and technical staff.

The survey was distributed electronically to all university structures, i.e. the following organizational units:

- faculties,
- non-faculty units,
- central administration and other units related to the activities of the university.

The survey questionnaire consisted of several sections, grouped into sections.

The first part entitled “METRICS” - four questions, answers to which provided the database necessary to characterize the population under study. This data is relevant from a research perspective, as indicated in an earlier study conducted among administrative staff at another university, which revealed that perceptions of ergonomic working conditions have a weak negative correlation with stress levels, with factors such as age, gender, working hours and

ergonomic conditions influencing perceptions, highlighting the importance of providing appropriate working conditions for employee health and safety (Oznur et al., 2023).

The second part required respondents to indicate to what extent they agreed or disagreed with the statement indicated. The theses presented are classified into four areas (Łochańska, 2020):

- WORK ENVIRONMENT - questions relating to employees' impressions and feelings about the environment of their workplaces, including infrastructure, work area, microclimate, signage, etc.;
- TECHNICAL EQUIPMENT OF THE WORK STATION - questions concerning the impressions and feelings of employees including the equipment of the work station, i.e.: type of furniture, possibility of its arrangement, compatibility, etc.;
- COMPUTERS AND SOFTWARE ERGONOMICS - questions relating to employees' impressions and feelings about the hardware used, i.e.: suitability of the equipment to the employee's work tasks, condition of the hardware, etc.;
- WORK ORGANISATION - questions about impressions and feelings of employees about the work organization, i.e. courses, training, the way work is done, etc.

A five-point Likert's scale was used to measure the claims, where:

- 1 - "definitely not",
- 2 - "rather not",
- 3 - "neither agree nor disagree",
- 4 - "rather yes",
- 5 - "definitely yes."

Computer hardware as a basic tool for university work

Additional questions were also included in the second part of the survey, which served to further explore the computer hardware aspect of the work, as many employees nowadays perform their tasks in front of a computer and this is particularly apparent at the university. Computer has become an indispensable and essential working tool, affecting not only the way tasks are carried out, but also efficiency and timeliness. In a higher education institution, hardware is a necessary work tool for administrative staff during basic working hours, while research and teaching staff, conducting scientific research, using computer software, performing analyses, creating publications, preparing teaching activities (presentations, assignments, handouts, etc.) also use desktop or laptop computers. While it might seem that working with hardware is pleasant and non-tiring work, this is not the case at all, and inadequate adaptation of the computer work station to the individual (and physical inactivity, body mass index, working hours, years of office work) (Aytutuldu et al., 2020) can lead initially to discomfort, ending in serious health problems (Malińska, 2019). The ailments most commonly experienced by employees who use the computer as a work tool are:

- neck pain (Malińska et al., 2012),
- upper and lower back pain (Aytutuldu et al., 2020; Author, 2019),
- upper and lower limb pain (Aytutuldu et al., 2020; Chowdhury et al., 2018),
- indispositions of the shoulder (Author, 2019),
- nervous and cardiovascular disorders (Bartoszek et al., 2018),
- visual disorders (Coles-Brennan et al., 2019; Zalat et al., 2012).

The longer we spend in front of a screen, the worse it is for our organism, therefore it is important to adjust the equipment of our workplace and the organization of our work so that we put as little strain on our organism as possible. Many of the causes of stress on the human body are physical factors of the work environment (such as lighting, air quality, noise or microclimate in offices and administrative workplaces) and are the main areas for shaping a safe, ergonomic and optimal workplace (Chen et al., 2020; Lou, Ou, 2019; Niciejewska, Kač, 2019). On the other hand, according to some other studies, most employees assess their internal physical environment as good, identifying lack of concentration and stress (Author, 2019; Lutke Lanfer et al., 2021) and organizational and social conditions (Karamanis et al., 2019) as factors of workload in the office. In addition, building and raising awareness among employees of the risk factors present in modern office work is still necessary to promote a general improvement of conditions of work from a physical and psychosocial perspective (Lutke Lanfer et al., 2021; Coelho et al., 2015).

A computer work station should meet the requirements of both safety and hygiene as well as, or even primarily, ergonomics (Ordinance of the Minister..., 1998). It is estimated that prolonged computer work in non-ergonomic conditions and poorly designed workstations at universities leads to problems with the upper limbs and trunk, as confirmed by the results of assessments of the magnitude of physical loads by methods, i.e. RULA and REBA) (Chowdhury et al., 2018). To avoid negative consequences of working at computer work stations, the following technical conditions should be met:

- ensuring adequate lighting, both natural and artificial,
- equipping office desks with curtains or roller blinds that reduce the likelihood of daylight reflecting on the computer screen,
- the height of a desk should allow for adequate positioning of office tools at the work station,
- the height of the table and the seat should be adapted to the needs of the employee and, above all, should allow the free position of the limbs and the correct observation angle of the monitor: 20-50°,
- the surface of the desk should be matt,

- the keyboard should be a separate piece of hardware and have an adjustable angle of inclination (0-15°),
- the monitor at the work station should have an adjustable tilt angle function (Ordinance of the Minister..., 1998).

As work stations at the university may be equipped with different hardware, information on the type of equipment was verified (Table 1, Figure 1).

Table 1.

Type of hardware used at individual work stations

Work station	Work performed on:		
	desktop computer	laptop	desktop and laptop computers
Administrative	62	6	16
Research	4	4	6
Research and teaching	27	33	101
Teaching	9	3	9

Source: Own study.

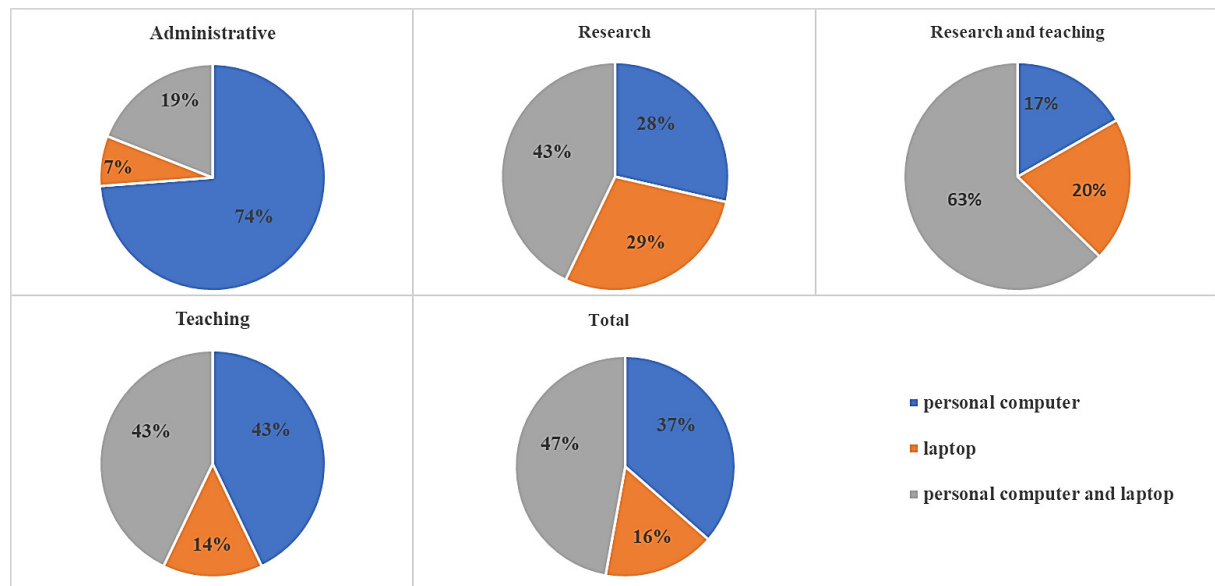


Figure 1. Type of hardware used at individual work stations.

Source: own study.

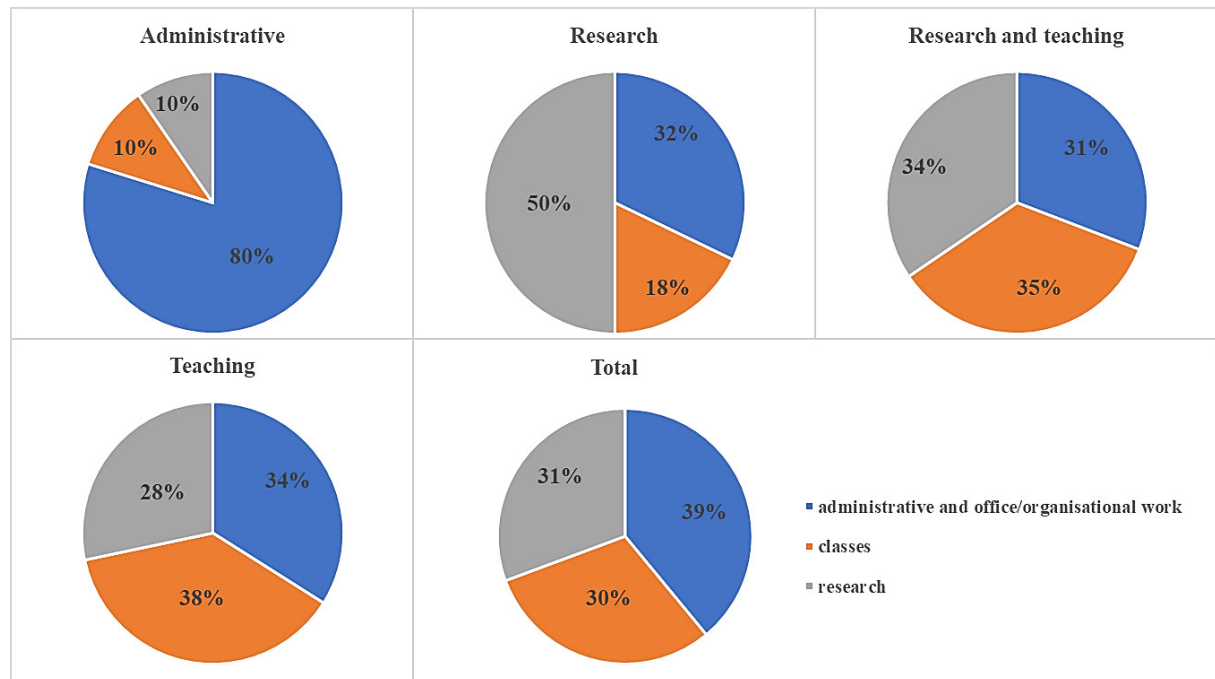
Three types of work performed by higher education staff using hardware were collated (Table 2 and Figure 2). The results obtained highlight that all positions are associated to varying degrees with the following tasks:

- office/administrative/organizational work,
- the preparation and delivery of teaching,
- preparation and conduct of scientific research.

Table 2.*The main tasks for which hardware is used in the various workplaces*

Work stations	Hardware use		
	administrative and office/ organizational work	classes	research
Administrative	83	11	10
Research	9	5	14
Research and teaching	142	160	159
Teaching	18	20	15

Source: Own study.

**Figure 2.** Types of work performed by particular groups of university employees using hardware.

Source: own study.

The employees' actual working time in front of the computer is shown in Table 3 and Figure 3. According to respondents' answers, this time is usually between 6 and 8 hours (47.1%). Working on a computer for more than 8 hours was indicated by more than 37% (including 80% of research and teaching staff).

Table 3.*Time of use of hardware by work station*

Work station	Actual working time at the computer		
	up to 4 hours	between 4 and 6 hours	between 6 and 8 hours
Administrative	3	11	59
Research	3	5	5
Research and teaching	3	16	61
Teaching	3	4	7

Source: Own study.

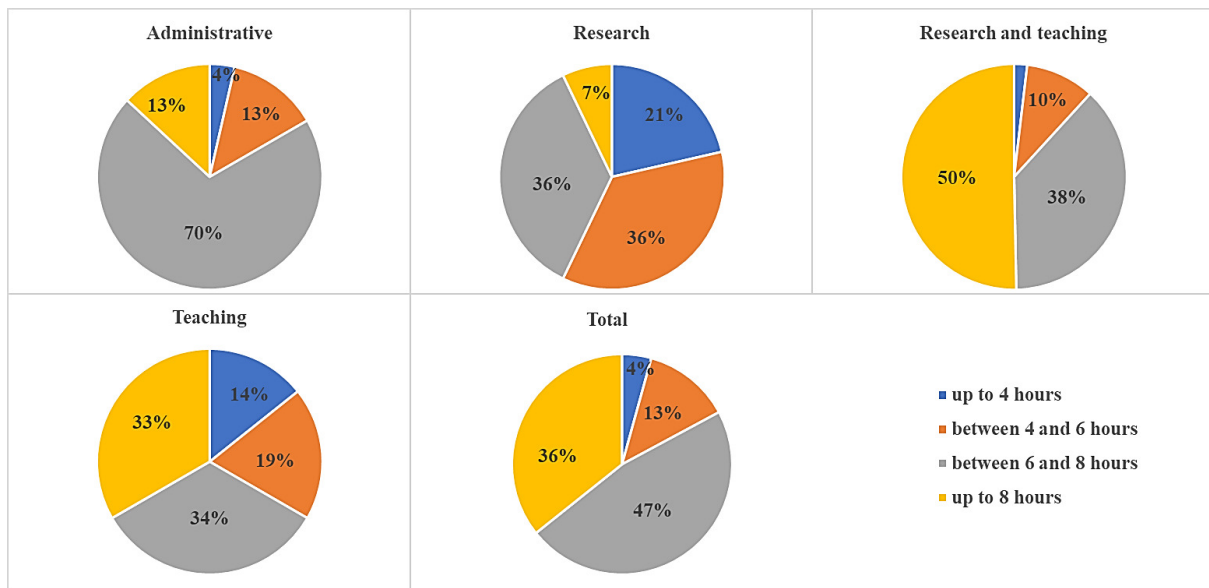


Figure 3. Percentage share of time spent working at the computer in individual workplaces.

Source: own study.

The compiled results indicate that there is a significant burden associated with prolonged computer work, especially among research and teaching staff. Such prolonged time spent in front of a screen can increase the risk of negative health effects.

3. Results

The questionnaire analyzed the level of safety and ergonomics at administrative, research, research and teaching positions, based on responses from 114 women and 166 men. The structure of the study population by age is shown in Figure 1. The largest group is between 31 and 40 years old (37.5%), these are young people but with a certain amount of work experience and seniority.

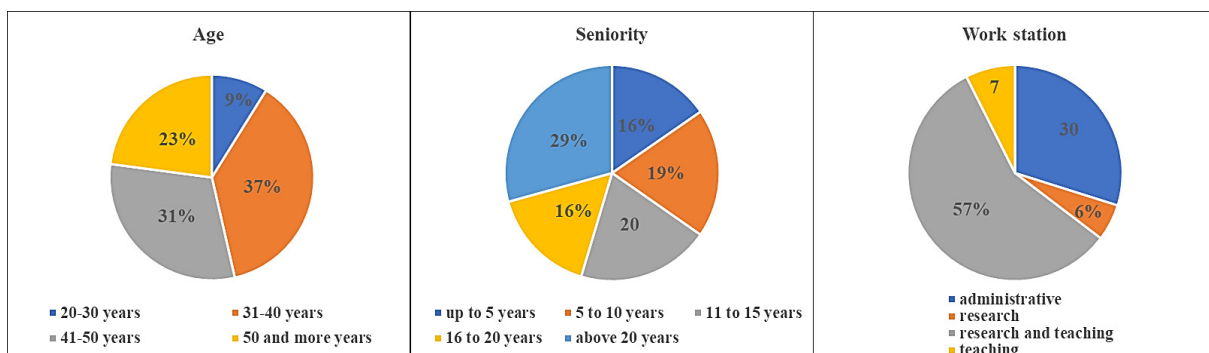


Figure 4. Percentage share of time spent working at the computer in individual workplaces.

Source: own study.

The least numerous group are people in the age bracket between 20 and 30 years (25 people). Among the respondents, employees with the longest work experience (over 20 years) constitute the most numerous group - 29.3% (Figure 4). Other groups by years worked are evenly represented in the range of 15-20%.

With regard to the diversity of staff positions held, 161 research and teaching staff (57.5%) completed the survey. Of the remaining respondents, 84 were employed in administrative positions and, in turn: 21 and 14 people - teaching and research staff (Figure 4), which is reflected in the employment structure of the university.

The second part of the survey asks about employees' impressions and feelings concerning the conditions of work within their own work stations.

3.1. Aspect - working environment

In the first instance, the questions concerned infrastructure, the area in which the sites are located, safety signage, room microclimates, lighting, noise and sanitary facilities. The results obtained are shown in Table 4 and Figure 5.

Table 4.
Respondents' answers concerning working environment

Selected aspect of the working environment	Points awarded and number of responses					Average score
	1	2	3	4	5	
Size of rooms	24	48	10	139	59	3.6
Ergonomics at the workplace	50	76	6	128	6	3.0
Room microclimate	43	77	8	123	29	3.1
Adequate lighting	14	39	6	158	63	3.8
Noise level	11	42	8	76	143	4.1
Cleanliness of the building and premises	7	13	5	161	94	4.2
Escape routes and exits	5	10	14	124	127	4.3
Cables and wires	23	41	16	134	66	3.6

Explanatory notes: 1 - "strongly disagree", 2 - "rather disagree", 3 - "neither agree nor disagree", 4 - "rather agree", 5 - "strongly agree".

Source: Own study.

The results of the survey indicate that employees of the technical university rate the maintenance of cleanliness and tidiness in their work environment the highest (91.1% - answers "rather agree" and "strongly agree"), indicating that this increases their comfort at work. In the second place, the signage system for escape routes was located (89.7%). The above may suggest that employees value a sense of safety at work and are confident that in the event of a situation threatening their health and life, the university is prepared to counteract dangerous incidents and will provide them with appropriate protection and assistance. The correct way of marking emergency exits together with the right system of lighting the escape routes in the workplace will make it possible to evacuate the danger area quickly but safely.

The lowest rating was given to the level of ergonomics at the work station (45% of respondents answered "rather not" or "definitely not"), and it is known that optimal solutions reduce the likelihood of pain resulting from overloading the muscular-skeletal system, so it is

particularly important at work in a sitting position, where the tool used is a computer (Figure 5).

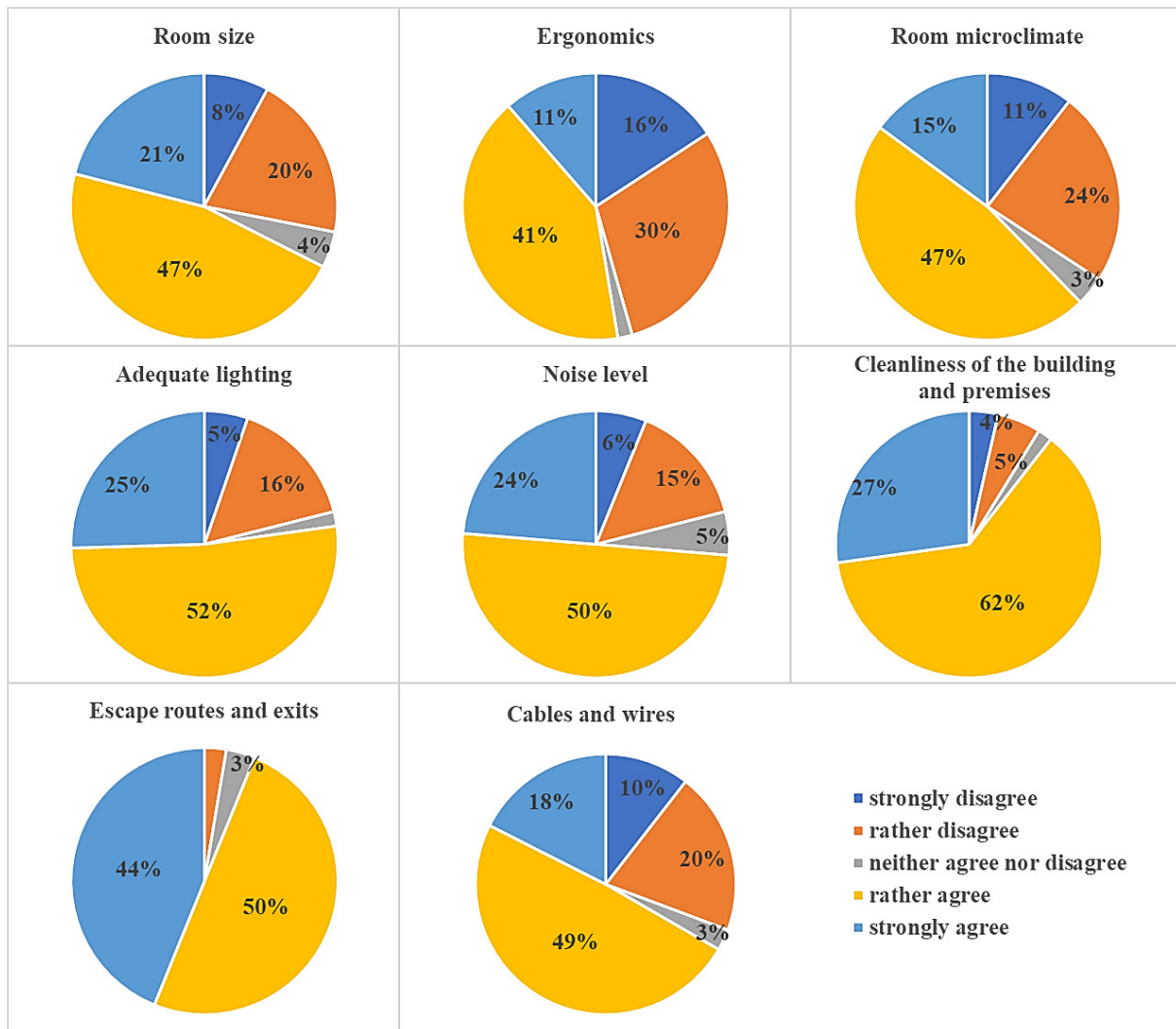


Figure 5. Structure of responses concerning the work environment.

Source: own study.

The results of the surveys carried out indicate a minimal divergence in the assessment of respondents' feelings about gender diversity.

3.2. Aspect - technical equipment of work stations

The second aspect analyzed in terms of employees' impressions and feelings are selected elements of the technical equipment of a given work station, i.e. the quality and type of furniture, the possibility of their convenient positioning, contributing to a more effective and comfortable work process. A quantitative summary of the responses is given in Table 5 with an illustration of these in Figure 6.

Respondents rated the state of window coverings in the workplace highest (81.5%), valuing comfort at work, noting that it is important for them to reduce the effects of excessive sunlight and daylight reflection on computer screens. In addition, individual work space, which allows

the necessary elements to be placed within reach of the upper limbs (76.4%), and office equipment and necessary equipment (i.e. computer, telephone, photocopying machine, printer, etc.), which have a significant impact on the quality and timeliness of the work performed (76.1% each), are highly valued. The weakest ratings were given to the seat parameters of stability and backrest height adjustment, although this is essential for reducing musculoskeletal disorders and injuries, with an average score of 3.3.

Table 5.

Respondents' answers concerning technical equipment of the workplace

Selected aspect of technical equipment at the workplace	Points awarded and number of responses					Average score
	1	2	3	4	5	
Quality of equipment	17	63	10	150	40	3.5
Workspace	15	38	12	158	57	3.7
Design of office equipment	21	34	12	133	80	3.8
Desk	27	44	7	146	56	3.6
Seat	48	54	3	113	62	3.3
Window coverings	25	22	5	99	129	4.0
Necessary equipment	17	40	10	119	94	3.8

Explanatory notes: 1 - "strongly disagree", 2 - "rather disagree", 3 - "neither agree nor disagree", 4 - "rather agree", 5 - "strongly agree".

Source: Own study.

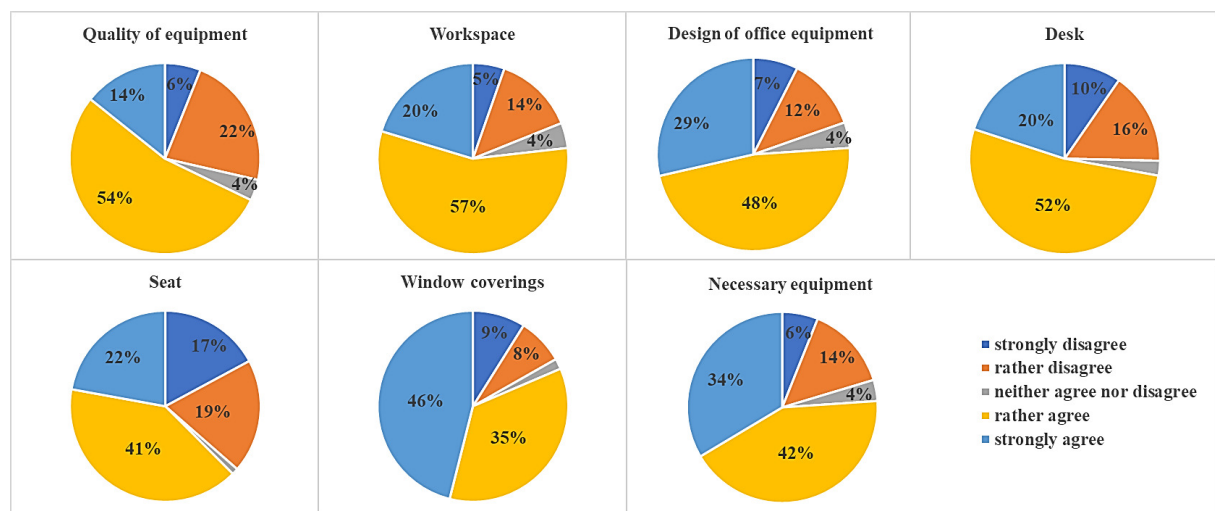


Figure 6. Structure of responses concerning the technical equipment of the workplace.

Source: own study.

After analyzing all the results of this aspect, it can be concluded that the university provides comfortable conditions of work for its employees. Employees rate the parameters related to the technical equipment of the workplace fairly positively.

3.3. Aspect - hardware and software ergonomics

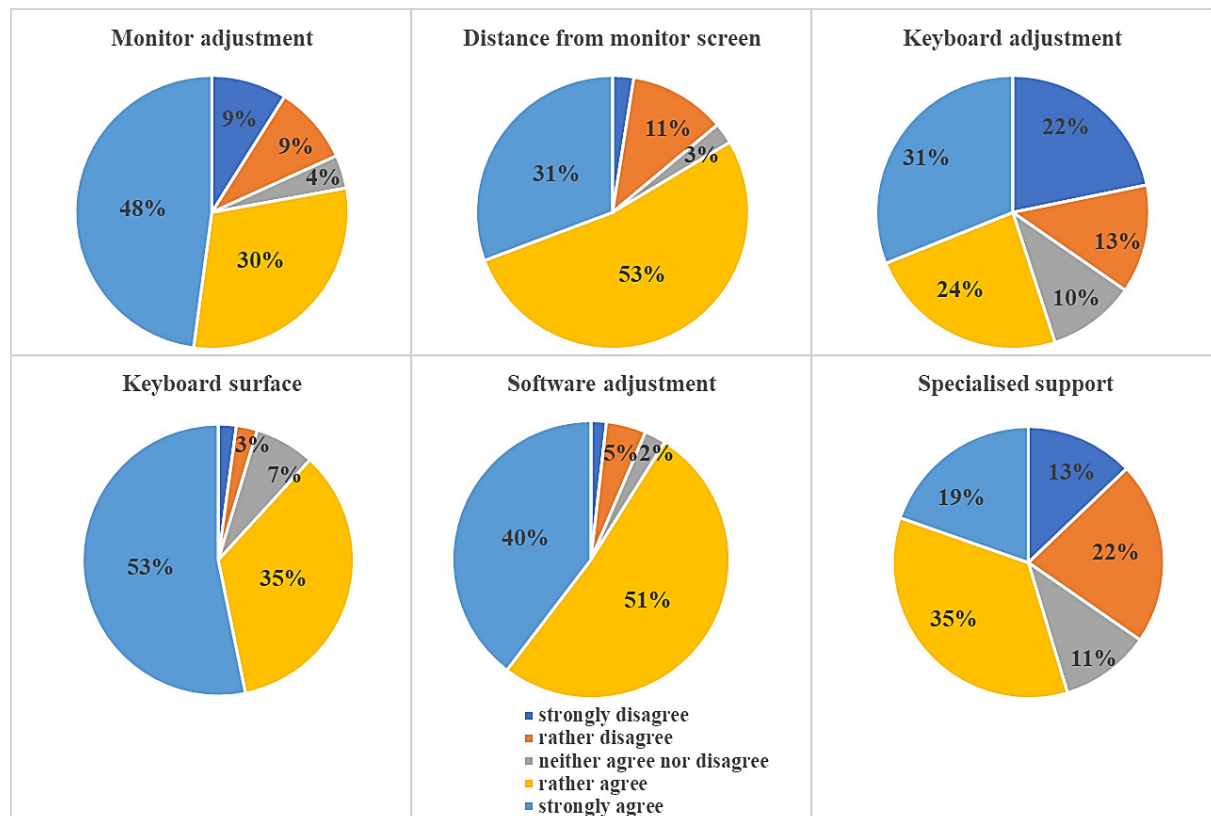
Another aspect analyzed in the questionnaire in terms of employees' impressions and feelings is the computer hardware and software ergonomics, i.e.: the condition of this hardware, the quality of the software and its adaptation to the psychophysical capabilities of the employee. The results obtained are shown in Table 6 and Figure 7.

Table 6.*Respondents' answers regarding hardware and software ergonomics*

Selected aspect of computer hardware and software ergonomics	Points awarded and number of responses					Average score
	1	2	3	4	5	
Monitor adjustment	25	26	11	84	134	4.0
Distance from monitor screen	7	32	7	148	86	4.0
Keyboard adjustment	61	36	29	67	87	3.3
Keyboard surface	6	7	20	98	149	4.3
Software adjustment	5	13	7	144	111	4.2
Specialized support	36	61	30	98	55	3.3

Explanatory notes: 1 - "strongly disagree", 2 - "rather disagree", 3 - "neither agree nor disagree", 4 - "rather agree", 5 - "strongly agree".

Source: Own study.

**Figure 7.** Structure of responses concerning computer hardware and software ergonomics.

Source: own study.

The research proves that respondents in terms of computer hardware and software facilities rated the availability of computer programs adapted to their tasks highest (91%). This is followed by the factor related to the keyboard surface and its features, i.e. matte finish, legibility of characters - 88.2% of satisfied people. The parameters related to the monitor, its adjustment and the distance between the eyes and the screen are highly rated - mark 4. The ability to adjust the keyboard angle was rated lowest by respondents (3.3 points) but most academics reported working on laptops, and here adjustment is difficult or impossible. The administrative staff mostly work on stationary equipment and here they rate their satisfaction with this parameter as good. Equally low (3.3) were assessed specialist assistance

in the event of the occurrence problems with software or computer operation. The lack of permanent support from specialists (IT specialists) may interfere, in particular, with the smooth and timely execution of tasks and research topics and contribute to stressful situations.

The analysis of the answers obtained shows that the system of computerization in the researched research and educational unit is at a very good level, but it should be emphasized that the development of technology, conducting innovative research, educating students, force constant updating and modernization of hardware and its software.

3.4. Aspect - work organization

Another aspect considered from the point of view of employees' impressions and feelings is the organization of work, which includes questions about breaks, freedom in the way they do their work, access to courses, training, conferences, and the extent of their work responsibilities and holiday periods. The results are presented in Table 7 and supported by Figure 8.

Table 7.
Respondents' answers concerning work organization

Selected aspect of organization of work	Points awarded and number of responses					Average score
	1	2	3	4	5	
Breaks at work	3	8	37	131	101	4.1
Courses, training	38	72	29	105	36	3.1
Autonomy of work	4	25	7	168	76	4.0
Business trips	29	51	23	126	51	3.4
Time of completion of tasks	47	75	21	111	26	3.0
Periods of leave	5	16	1	130	128	4.3
Variety of tasks	3	25	9	136	107	4.1

Explanatory notes: 1 - "strongly disagree", 2 - "rather disagree", 3 - "neither agree nor disagree", 4 - "rather agree", 5 - "strongly agree".

Source: Own study.

The respondents' answers indicate that the strongest point for employees in the area of work organization is the compliance with the law on the possibility to choose the timing of annual leave (92.1% good and very good ratings) by the management team. According to the respondents, the possibility to decide how to perform their work in a given position (work autonomy - 87.1%) and breaks during work (82.8% satisfied) are at a satisfactory level. Factors that need to be improved include: ensuring greater accessibility and opportunities to participate in specialized courses, training to broaden professional skills, and adjusting the scope of responsibilities and work tasks to their specific time. It should be remembered that professional development of employees, through additional courses/workshops, influences greater commitment to work, although it consumes more working time, but it can support the prevention of routine, monotony or occupational burnout (Grala, 2020).

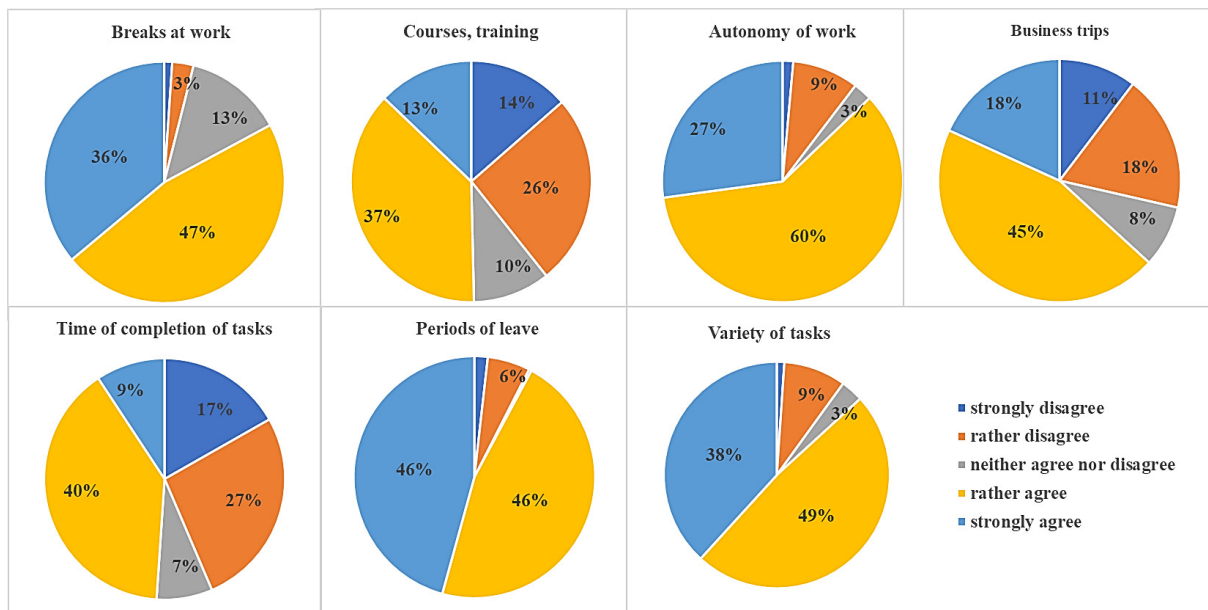


Figure 8. Structure of responses concerning the work organization.

Source: own study.

Irrespective of gender, respondents are negative about the time taken to complete duties and tasks (men: 2.8 and women: 3.3 points - representing 33.6% dissatisfied). Task and courses/training completion time is the issue least rated by teaching and research and teaching staff (below 3 points). These are people who teach both full-time and part-time students, so they do their work during the week and at weekends. The survey was conducted in the early days of the Covid-19 related pandemic and the work at the university was done remotely - this presented a major challenge for the teaching staff, involving more time spent preparing for such a form of work. Only for the group of people employed in administrative positions are additional professional development events (courses, training, etc.) rated as satisfactory.

4. Discussion and conclusions

The article thoroughly analyses the problem of working environment conditions for employees of a technical university as a scientific and educational unit. The main focus was to identify areas for analysis of the design of conditions of work, with particular emphasis on aspects of work with hardware, in administrative, research, research and teaching positions. The analysis was based on the impressions and feelings of the employees themselves, as expressed in the survey carried out.

The management of health and safety at work is an extremely important process in any institution, including a research and teaching unit, and requires a great deal of commitment from the employer to ensure an adequate level of protection from hazards and their effects on both the physical and mental health of employees. The questions asked in the survey made it

possible to determine the level of satisfaction and dissatisfaction of employees with the state of safety and ergonomics at their work stations and to identify aspects for improvement. It appears that safety and ergonomics are important for employees, as adequate levels reduce the likelihood and severity of physical ailments and increase comfort at work, productivity and work satisfaction.

The most significant conclusions of the research and analysis include:

1. In each of the indicated areas of conditions of work, there are aspects to be improved: work environment - ergonomics at the work station (average score of 3.0 out of maximum 5.0), technical equipment of work stations - seating (3.3), hardware and software ergonomics - keyboard adjustment and specialized support (3.3), and work organization - task completion time (3.0).
2. The highest rated employees were: work environment - escape routes and exits (mean score of 4.3), technical equipment of workplaces - window coverings (4.0), hardware and software ergonomics - keyboard surface (4.3) and work organization - holiday periods (4.3).
3. The results obtained regarding the use of hardware and the organization of the computer work station, which, because the study was conducted at the beginning of the pandemic, reflected the state and level of the working environment at the university during its normal operation. Surveys carried out afterwards would not have been able to establish the actual state of safety and ergonomics in the opinion of the employees interviewed, as they worked for a longer period of time in a remote system.

To summarize, the level of safety, including the condition of ergonomics, at the surveyed higher education institution requires some changes, first of all in the aspects indicated by employees and regular monitoring of employee opinion on conditions of work.

Continued research in the coupling of satisfaction and existing complaints due to existing conditions of work may provide suggestions for prioritizing preventive measures in the workplace from an early stage in the design of computer-friendly work stations at the university. In the future, it is planned to carry out a comparison of the actual working conditions at the workstations with current Polish and EU legal standards, which will allow the nature of any shortcomings to be identified more accurately. In addition, the extension of the research to other universities and the inclusion of work observations will enable an even more complete assessment of factors affecting employee comfort and health, also in the context of pandemic-related changes.

Acknowledgements

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MANAGERIAL COMPETENCIES IN SUPPLY CHAINS FOR INDUSTRY 5.0

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Purpose: The purpose of this article is to identify the key managerial competencies necessary for supply chain management in the context of Industry 5.0. The study attempts to identify which skills are particularly important for leaders in the medical device manufacturing sector under conditions of digital and organizational transformation.

Research methodology: the study used a diagnostic survey method, based on a CAWI questionnaire, addressed to a purposively selected sample of 34 senior managers - including logistics and purchasing directors and business owners from Polish and foreign markets. A three-level Likert scale was used to assess competencies.

Results: Problem solving was considered the most important managerial competency - indicated in unison by the majority of respondents from both groups. Creativity, balanced thinking, clear communication and creating an open work environment were also highly rated. Slight differences were also revealed between domestic and foreign respondents in such competencies as decision-making and delegating tasks in a digital environment.

Research limitations/implications: A limitation of the study is the small and non-random survey sample resulting from the purposive selection of respondents. The results can form the basis for further quantitative research and in-depth qualitative analysis, as well as cross-industry and cross-cultural comparisons.

Practical implications: The findings can serve as a guideline for HR departments and talent development managers when planning strategies for training, reskilling and upskilling executives in digital supply chains. The identified competencies should be integrated into HR management policies.

Social implications: the study underscores the importance of social and emotional competence in the era of digitization, supporting the human-centric approach of Industry 5.0. This can contribute to building a more empathetic and sustainable work environment.

Originality/value: The article brings a new perspective to the literature on competency management in the context of Industry 5.0, focusing on the practical insights of leaders in the medical device manufacturing sector. It provides value to researchers, management practitioners and HR policy designers.

Keywords: managerial competence, supply chain, Industry 5.0, healthcare industry, digital transformation.

Article category: research article.

1. Introduction

There are many definitions of managerial competence in the literature. There is a lot of controversy about the understanding of the concepts associated with the buzzwords manager, leader, leader. Some authors put an equal sign between these categories, others try to distinguish a different definition for each buzzword. This is certainly due to the specifics and nature of the work environment in which managers, leaders or leaders move. According to Penc, a manager is a person who manages the work of others within the established structure of an organization (Penc, 1997, p. 188). Griffin, on the other hand, points out that a manager is a person responsible for implementing the functions of management: planning, organizing, leading and controlling (Griffin, 2005, p. 7). Crow AND Prokopovich point to Mintzberg, who proposes blurring the boundaries between the roles of leader and manager. He believes that instead of separating, for example, management from leadership, we should consider managers as leaders and leadership as management done well (Wrona, 2016; Prokopowicz, 2022). Arguably, managerial skills are conducive to the role of both commander and leader (Balcerzyk, Žukovskis). In the studies of the last few years (Murphy, Poist, 2006; Shou, Wang, 2017; Pereira, Sheta, 2021) in the field of management, one could find a relevant set of managerial competencies in relation to Industry 4.0. Only recently with the EU Industry 5.0 report has the topic of managerial competencies started to be explored in terms of humanocentricity, resilience and organizational sustainability. The topics addressed, and in particular the research conducted, fill a research gap concerning the role of managerial competencies in Industry 5.0. As indicated above, no research has been conducted to date on the importance of managerial competencies in the context of Industry 5.0. It is therefore reasonable to ask what significance the identified managerial and emotional competencies have in the era of digitalization, supporting the human-centered approach of Industry 5.0? The structure of the article corresponds to the need to justify the research gap. Managerial competencies in supply chains were characterized, along with a relevant review of the literature on the Industry 4.0 era, which initiated the emergence of requirements for managers and their skills. Then, based on the identified research gap, a literature review was conducted and a proprietary set of competencies for Industry 5.0 was proposed. The next stage was to present the characteristics of the research and the industry in which it was conducted, and to determine the relevance of the selected medical equipment industry. The article concludes with a discussion and conclusions and recommendations that clearly indicate the importance of managerial competencies in Industry 5.0.

2. Characteristics of managerial competencies in supply chains – a review of the literature

In the research proposals for managerial competencies or the development of existing managerial competencies themselves, a stronger integration of managers with corporate orientations is apparent, treating work as a project and the organization as one project and as a set of projects. This is to deepen the relationship with the environment, through a greater level of technological integration, flows of standardized and normalized data in supply chains and, consequently, in entire value chains (Ribeiro et al., 2021; Prokopowicz, 2022).

The Digital Fastforward (2020) report points out that in order to successfully navigate the future work environment, leaders must realize that the assumptions they have made may be wrong. This means prioritizing new ideas and rapid change based on what they have learned so far. Managers, given the increasingly turbulent economic environment, must remain open to feedback and change. This approach is at the heart of the re-imagining of new work opportunities and how to operate in an uncertain future. Many works also note the context of the virtualization of companies' operations and the often remote work of managers and professionals (Pilipchuk, 2020). However, it should be noted here that this approach is characteristic of certain industries. There remains a whole host of industries where humans are indispensable despite the use of smart solutions or the creation of factories of the future.

Reviewing the literature, the authors of the study decided to identify basic definitions of managerial competencies in supply chains in the context of Industry 4.0 and their further evaluation in relation to Industry 5.0.

2.1. Managerial competencies in supply chains in the context of Industry 4.0.

In the case of identified managerial competencies suitable for the development of Industry 4.0, several examples can be pointed out. According to the concept of Industry 4.0, all data relevant to enterprises is to be collected and analyzed, which is supposed to distinguish them from most modern enterprises and supply chains, which, however, due to capital and technological constraints cannot afford to do so (Shaba et al., 2019). According to Pereira and Sheta (2021), the set of managerial competencies that would address the challenges of developing enterprises and supply chains in the Industry 4.0 environment are: agility, entrepreneurial intelligence, business savvy, design thinking, breakthrough leadership, collaborative and problem-solving and decision-making mindset, and research orientation.

Murphy and Poist (Murphy, Poist, 2006), based on an analysis of data obtained from 32 U.S. head hunters of recruitment firms that specialize in recruiting managers in logistics, transportation, supply chain management and related fields, distinguish three types of skills for logistics and supply chain managers: business, logistics and management.

1. Business includes knowledge of various areas of business such as economics, psychology sociology.
2. Logistics skills related aspects such as transportation, warehousing, inventory management and supply chain operations.
3. Management skills relating to planning, organizing and coordinating logistics activities along with personal attributes such as leadership, communication and problem-solving skills.

Gammelgaard and Larson distinguished among managerial competencies: ambition, critical reasoning, decision making, ethics, listening, motivating, organizing, presentation skills, prioritizing, problem solving, self-learning, self-discipline, speaking/oral communication, time management, training (training), written/written communication. Managerial competencies, according to these authors, can also include basic supply chain management (SCM) skills, i.e. the ability to see the big picture, which refers to the ability to understand and analyze the overall context, goals and objectives of a situation or organization, change management, trust and credibility, awareness of interdependencies and interconnectedness (of functions and departments of an organization), leadership, knowledge of the industry (best practices, regulations, major players), negotiation skills, language skills, organizational culture, project management, SCM awareness, teamwork, knowledge of the latest technologies and techniques.

In addition, Shou and Wang (2017) through a survey of job advertisements in various countries (900 samples in total) introduced a very broad catalog of competencies and introduced the category of general skills, functional skills, SCM qualifications and leadership, SCM expertise, and industry and senior management skills (Shou, Wang, 2017). Among managerial competencies, they listed soft skills such as communication and coordination, supply chain management qualification and leadership i.e. knowledge of SCM principles, ability to lead SCM initiatives.

Similar conclusions were reached by shadowing studies. Researchers collected and documented observation material. For 10 selected days over six weeks, three researchers observed the work of two managers each (for a total of six managers). The material provided detailed insight into the managers' activities, interactions and decision-making processes in their daily work. Logistics and supply chain managers use a combination of business, general and behavioral managerial competencies in practice, making up a certain competency profile (Derwik et al., 2016). The authors note that it goes beyond supply chain management expertise. The profile consists of:

1. general competence, as opposed to specialized competence;
2. multitasking competence (working with multiple computer screens, cell phones and phone interruptions and employees seeking advice;

3. a bundle of different types of competencies beyond those mentioned in 1 and 2 using synergies. Managers actually use competencies in combination with each other, leading to synergistic effects. For example, in problem solving, managers also combine information gathering skills and company experience to find better solutions faster;
4. company experience - identified as a separate competency, but rarely mentioned in the literature. Experience and knowledge of the company's policies, history of customers, suppliers helps in setting tasks in personnel management.

Based on a survey (Prajogo, Sohal, 2013) of 145 Australian supply chain managers, competencies and skills were identified that need to be developed among supply chain professionals to significantly improve supply chain efficiency and integration. Communication and teamwork skills, as well as knowledge of a wide range of technologies, were identified as the most important.

A review of research on the competencies of logistics and supply chain managers suggests that competencies unique to supply chain managers include areas such as business, logistics, interpersonal management, technological competence, functional competence, SCM knowledge, and industry skills (Derwik, Hellström, Karlsson, 2016).

Supply chain managers are critical to the global economy. They represent a unique discipline responsible for supporting the global delivery network of products and services throughout the supply chain, from raw materials to end customers. Specifically, supply chain managers engage in the design, planning, execution, control and supervision of supply chain activities to create net value, build competitive infrastructure, leverage global logistics, synchronize and manage the supply chain (Apics, 2014). The Apics Association has created a diagram of managerial competencies related to professional affiliation (training, certifications, MBA), profession (skills required for the position such as supply chain manager) and the foundation of managerial competencies (skills and abilities that allow individuals to function in an organizational environment such as personality traits, acquired knowledge).

With the development of the concept of Industry 4.0 and its evolution to the concept of 5.0, attention began to turn to the context of corporate social responsibility and sustainability. According to Rego, Pina and Polonia (2017), leadership competencies should focus on visionary, interdisciplinary and self-leadership (Zaleśna, 2019).

Meier (202) points out that the development of managerial competencies in supply chains is carried out in two dimensions: *fusion skills* and competence enhancement through a competence argumentation strategy. Both are related not only to managerial competencies, but also to the development of machine competencies, which is part of the Industry 4.0 trend (Prokopowicz, 2022).

The approach mentioned earlier in the introduction (Ribeiro, Amaral, Barros, 2021; Prokopowicz, 2022; Rego, Pina, Polonia; Grzybowska, Lupicka, 2017) to managerial competence can also be applied to supply chains.

Below is a table with selected views on managerial competencies in supply chains in the context of Industry 4.0.

Table 1.

Views on managerial competencies in supply chains in the context of Industry 4.0

Author(s)	Views regarding managerial competencies in supply chains in the context of Industry 4.0.
Murphy, Poist (2006)	Three types of skills for logistics and supply chain managers: business including knowledge of various business areas, logistics related aspects such as transportation, warehousing, inventory management and supply chain operations and management skills relating to planning, organizing and coordinating logistics activities along with personal attributes such as leadership, communication and problem-solving skills.
Gammelgaard, Larson (2001)	Core managerial competencies include ambition, critical reasoning, decision making, ethics, listening, motivating, organizing, presentation skills, prioritizing, problem solving, self-learning, self-discipline, speaking/oral communication, time management, training (training), written/written communication.
Shou, Wang (2017)	Among the managerial competencies listed soft skills such as communication and coordination, qualifications and leadership in supply chain management i.e. knowledge of SCM principles, ability to lead SCM initiatives.
Derwik et al. (2016).	Logistics and supply chain managers put into practice a combination of business, general and behavioral managerial competencies, making up managerial competency profile.
Prajogo, Sohal (2013)	The most important managerial competencies were considered to be communication and teamwork skills and knowledge of a wide range of technologies.
Shet, Pereire (2021)	The proposed set of managerial competencies in Smart organizations are: agility, entrepreneurial intelligence, business proficiency, design thinking, breakthrough leadership, collaborative mindset, strong attitude on problem solving and decision making, research orientation.
Apics (2014)	A diagram of managerial competencies related to the affiliation of the profession (training, certificates, MBA), the profession performed (skills required for the position, e.g., supply chain manager) and the foundation of managerial competencies (skills and abilities that allow individuals to function in the organizational environment such as personality traits, acquired knowledge).
Ribeiro, Amaral, Barros (2021)	In the research proposals for managerial competencies or the development of existing managerial competencies themselves, a stronger integration of managers with enterprise orientations, treating work as a project and the organization as one project and as a set of projects, is evident. This is to deepen relationships with the environment, through a greater level of technological integration, flows of standardized and normalized data in supply chains, and consequently in entire value chains.
Digital Fastforward (2020)	to successfully navigate the future work environment, leaders must realize that the assumptions they have made may be wrong. This means prioritizing new ideas and rapid change based on what they have learned so far. Managers, given the increasingly turbulent economic environment, must remain open to feedback and change. This approach is at the heart of the re-imagining of new work opportunities and how to operate in an uncertain future.
Rego, Pina e Cunha (2017)	leadership competencies should focus on visionary, interdisciplinary and self-leadership.
Meier (2021)	The development of managerial competence is carried out in two dimensions: <i>fusion skills</i> and competence enhancement through competence argumentation strategy. Both are related not only to managerial competencies, but also to the development of machine competencies, which is part of the Industry 4.0 trend.
Grzybowska, Łupicka (2020)	The new managerial competencies are an extension of all the already known competencies: creativity, decision-making, problem-solving, conflict resolution, analytical skills, research skills, efficiency orientation.

Source: own elaboration.

2.2. Managerial competencies in supply chains in the context of Industry 5.0.

Analyzing the arguments of academics and practitioners to date, a certain paucity of demands for managerial competence in the areas of humanocentricity, sustainability or the resilience of companies and supply chains to the surrounding economic environment becomes apparent. A shift away from the main demands of Industry 4.0 towards digitalization is clearly marked. Therefore, after analyzing the available articles, reports and compact items, a new, more detailed set of managerial competencies is drawn to meet the challenges of Industry 5.0.

Today's managers in enterprises and supply chains to meet the demands of maintaining organizational resilience or sustainability activities must be flexible in their competencies. Depending on the given situation, managers apply an appropriate set of managerial competencies. The following table shows the most desirable competencies in the Industry 5.0 era as defined by the literature and previous arguments about the managerial competencies of the 4.0 era Based on the literature review (European Commission et al., 2021; McLaren, 2021; Audrey, Paksi, 2021; Dwivedi et al., 2023; Song et al., 2021; Knut, Balaji, 2013; Gartner, 2023; APICS, 2014; Hoffman et al., 2005; Relich, 2015; Joerres, McAuliffe, 2016; Winter, Heindl, 2016; Davis et al., 2011; Bauer et al., 2015; Störmer et al., 2014; Pompa, 2015) listed the most commonly identified managerial competencies relating to supply chains in the 5.0 economy era. listed the most commonly identified managerial competencies relating to supply chains in the 5.0 economy era. The shape of these competencies has evolved over time. Most of the works focused on supply chain competencies, without highlighting the role of sustainability economics. Much of the work focused on competencies in relation to Industry 4.0 (Hoffman et al., 2005; Joerres, McAuliffe, 2016; Störmer et al., 2014; Morgan, 2014). After a deeper analysis of the literature, 16 managerial competencies have been identified (Tajbakhsh, Hassini, 2015; Adams et al., 2021; Da Silva et al., 2019; de Janasz et al., 2014; Park, Faerman, 2019; Baron, Markman, 2000; Audrey, Paksi, 2021; Song et al., 2021; Morgan, 2014) that are required by companies establishing supply chains in the 5.0 economy. They are listed below in the table in sequence with a description. Their relevance to aspects of Economy 5.0 has been taken into account. Of course, this set of competencies can also be used for traditional supply chains, but the authors believe that these 16 managerial competencies are particularly predestined for the requirements of Industry 5.0 supply chains.

Table 2.*Managerial competencies in supply chains in the context of Industry 5.0.*

Lp.	Managerial competence	Description
1	Ability to organize time	In the age of the digital economy, time planning is becoming one of the factors for survival and success in a turbulent economic environment. Time management is all about the ability to plan, organize and effectively use available time to achieve goals and complete the tasks ahead. What is important is how we schedule the time both needed to meet commitments to work and the personal time needed for our own psychological well-being (Seiwert, 1998).
2	Balanced thinking	The ability to perceive deeper meanings and hidden senses taking place in the economy. The human mind is guided by established patterns, routine tasks, which does not allow for a more insightful discernment of reality. Sustainable thinking requires managers to go beyond the beaten patterns and take control of their own limitations
3	Innovative and adaptive thinking	Innovative thinking that streamlines adaptation to constantly occurring changes. Successful innovations improve products or processes and ultimately lead the company to a leadership position in the market. The main determinant of innovation, is the strength of competition between companies in the industry (Golej, http://www.instytut.info/IIIkonf/referaty/1c/golej.pdf , 17.03. 2012).
4	Collaboration in a virtual environment	The ability to work productively and with commitment as a member of a virtual team. Cooperation in a virtual environment is encroaching more and more on the activities of companies in many different sectors of the economy. Such an approach is being forced by the economic situation related, for example, to the search for unique resources, often available on the other side of the world. Virtual meetings make it possible to conclude agreements at a distance, but for this to happen a certain set of skills characterizing a competent manager is needed. An effective manager in conducting virtual meetings should skillfully develop a common vision and goals for a cooperating team on two different ends of the world.
5	Creativity	Creativity is characterized by the ability to see the world in new ways, find hidden patterns, make connections between seemingly unrelated phenomena and generate solutions. A creative manager uses both his knowledge, creative thinking skills and motivation. Knowledge refers both to knowledge of procedures, technical knowledge but also to intellectual qualifications.
6	Troubleshooting	Problem solving requires both analytical and creative skills. Analytical or logical thinking includes skills such as comparing, evaluating and choosing. When solving problems, patience and flexibility are key. In particular, managers managing complex supply chains need to demonstrate a logical approach to solving problems. This cannot lack such elements as understanding the problem, analyzing the available information to analyze the situation, creating an action plan and implementing it, monitoring progress in solving the problem and evaluating the results.
7	Decision-making	Decision-making is the process of making choices by identifying decisions, gathering information and evaluating alternatives. The decision-making process requires clear and precise communication in which all risks and prospects are taken into account. Every problem is different, but the techniques and methods used to solve them should be methodical and focus on several steps, avoiding constant crisis and hasty decisions.
8	Research skills	Research skills can come from the need to use reliable sources for continuous learning in a changing environment. Researcher's skills are primarily the ability to think critically by properly evaluating information their verification and drawing relevant conclusions. In an age of information overload, it is also important to extract reliable data from available documents, interviews or lectures and discussions.

Cont. table 2.

9	Analytical skills	Analytical skills are the ability to visualize, gather information, express, analyze, solve complex problems and make decisions. In a business context, they are invaluable because they provide a deeper understanding of data, market trends, customer needs and many other aspects that are critical to a company's success. These skills include logical thinking, the ability to draw conclusions, evaluate situations and predict potential outcomes (https://bigglo.pl/slownik/czym-sa-umiejetnosci-analityczne/ , 23.05.2024).
10	Creating an open environment	Encouraging employees to work together to solve problems and improve business practices. Creating an open environment requires managers to use a variety of leadership styles including democratic and authoritarian. It is particularly helpful to choose those characteristics of a particular style that will offer mutual trust, making employees feel that they are taken seriously by their superiors. An open environment is also fostered by open communication characterized by the ability to freely express one's own opinions and ideas.
11	Communicating clearly to avoid misunderstandings	Clear, simple and understandable language of speech allows for faster transmission of commands and enforcement. Managers should use clear, simple and understandable language of speech which allows for faster transmission of orders and enforcement. Avoiding complicated words and whole phrases will make it easier to communicate with employees. Not always particularly developed erudition is a desirable trait for a managerial position. It is definitely better to express yourself in a way that the recipient can understand. You should also avoid ambiguity and make sure that the sentences you formulate make sense and will not be understood otherwise.
12	Negotiation skills	The ability to use different methods of negotiation effectively leads to compromise or negotiating advantage. An important role in negotiating is played by the attitude we adopt. A positive attitude toward negotiation as a tool for human resource management can be expressed, among other things, by attempting to conduct negotiations, the frequency with which they are conducted, commitment to implementation and adherence to the agreements made. In the case of a negative attitude, there is the use of other forms of management, such as more directive, authoritarian ones. If negotiations are perceived as a fair way of enforcing and protecting employee interests, the supervisor treats them as an effective management tool, enjoys this form of contact with co-workers, this will promote the formation of mature negotiating competencies of managers (Kowalczyk, 2013).
13	Ability to delegate authority to employees at lower levels	The enormity of information forces the delegation of some tasks and decision-making to lower levels of employees. The ability to delegate authority to employees at lower levels is inextricably linked to a given manager's personality traits, self-esteem and skills. This is a trait that people in managerial positions should possess in these digitalized times. It is incumbent on those who delegate work to employees to keep abreast of advances in the economic sphere and the digitization of the environment, and this means that managers or executives are often unable to reconcile professional management with keeping up with the dynamic development of new technologies. Therefore, there is an objective need, that the tracking of progress, the initiation of changes, their adaptation to the conditions of a particular organization and implementation are handled, in addition to leaders, primarily by lower-level specialists and employees delegated to such tasks (Oleksyn).
14	Posting employees to jobs according to their skills suited to working in the digital economy	Managers and supervisors are required to provide "comfort" to employees, showing them the way to achieve the right digital skills. Managers and supervisors are tasked with posting employees according to their skills suited to working in the digital economy.

Cont. table 2.

15	Performance orientation	An "efficiency" approach is one that emphasizes the efficient use of resources as the main determinant of decisions and actions. Every manager, as mentioned earlier, should skillfully delegate tasks to employees, depending on their professional competence. What matters in this case is performance orientation, that is, planning tasks in such a way as to make the most effective use of employees' skills. This is not an easy task, especially when dealing with newly hired employees. Individuals hired for a particular position may have specific skills suited to the job, but sometimes it may turn out that a particular employee has other valuable competencies to perform completely different tasks. Therefore, a manager or team leader is also expected to take a close look at subordinates and delegate work according to their skills.
16	Entrepreneurship	Entrepreneurial thinking skills refer to the ability to identify market opportunities and discover the most appropriate ways and times to exploit them. Rather, it is a state of mind that opens one's eyes to new opportunities. Entrepreneurship is inextricably linked to the learning organization. Entrepreneurial thinking skills refer to the ability to identify market opportunities and discover the most appropriate ways and times to exploit them. It is a kind of state of mind that allows to look more broadly at new opportunities. To develop a mind for new market opportunities one must constantly learn about the market, customers and lurking competitors.

Source: own elaboration.

3. Research methodology

The authors of the article decided to conduct a survey of a purposively selected research group. The group consisted of senior managers managing logistics and supply chains in manufacturing companies (directors of logistics and purchasing departments) and owners or CEOs of manufacturing companies in the medical industry. This made it possible to reach respondents who, by virtue of their positions, should have knowledge of key managerial competencies. This selection of respondents involved conducting the survey on a smaller, non-random sample, but allowed for objective results due to their extensive knowledge and professional experience, as well as their leadership of teams on an international scale. A total of 34 respondents took part in the survey, 20 from the Polish market and 13 from the global market. Only senior executives were selected for the study, a larger research sample was beyond the research capabilities of the authors of the article. The questionnaire was distributed after direct contact by email or telephone to explain the purpose of the survey, how it would be conducted, and the significance of the research area. At the same time, substantive and technical instructions were provided. The questions in the survey were developed based on literature reviews and previous pilot studies conducted in 2017 and 2018 (Łupicka, Grzybowska, 2017, 2018). This allowed us to review the existing questionnaires and modify them with additional important questions concerning managerial competencies in the Industry 5.0 environment. The companies participating in the survey were located in Europe, North America and East Asia and had diverse manufacturing operations in the medical device industrial sector.

The survey was conducted in June 2023. The survey questionnaire was prepared in electronic form. It was distributed to the companies via Internet mail. Respondents were assured of anonymity. The survey used the CAWI (Computer-Assisted Web Interview) method, in which the participant is asked to complete the questionnaire electronically. The survey used a three-point Likert scale, where 1 meant unimportance of a given competence, 2 hard to say and 3 importance of a given competence. Three-point scales communicate two pieces of information (neutrality and direction). When asking respondents to take the survey, care was taken to ensure credibility and trust in the researcher and the survey being conducted. The survey did not include "sensitive" questions and was conducted in accordance with the Code of Ethics for Research Workers (Commission on Ethics in Science (2020) and general rules regarding RODO.

4. Industry characteristics

According to Fortune Business Insights, the global medical device market was worth \$425 billion in 2018. It too is projected by the institution to expand by another 190 billion by 2025, growing at just over 5 percent year-on-year. This growth is being driven by both demographic and lifestyle changes and the resulting health consequences, as well as aging hospital infrastructure (PARP - report2021)

In a short time, one-fifth of the total population in the European Union will be senior citizens, in Japan, for example, as many as one-third. An aging population and a growing global population will cause it to grow by another billion over the next decade, to 8.6 billion people, reaching nearly 10 billion by 2050 - not the only challenges health systems will have to face.

Unhygienic lifestyles, lack of physical activity and unhealthy, junk food promote obesity, insulin resistance, diabetes and heart disease and cancer. In China and India alone, the number of diabetics is estimated at 200 million. Worldwide, there are already more than 400 million, and that number is expected to increase by half in the next dozen years. According to the WHO (World Health Organization), there were 466 million deaf and hard-of-hearing people in 2018, representing an ever-growing market for hearing aids and assistive listening devices. Health problems are not the only scourge of modern societies, the other huge problem is aging, often depleted hospital infrastructure. In Europe and the United States, the main challenge in this area is to use modern technology, among other digital technologies, to reduce costs while increasing accessibility and raising the quality of health care. The medical device market includes the sale of equipment and accompanying services such as maintenance, rental and training. The main users are patients and medical personnel in healthcare facilities. The devices are used for diagnosis, therapy, monitoring and prevention. This market is distinguished by high regulatory

requirements, including environmental ones, which entails going through costly and time-consuming certification processes.

5. Test results

Analyzing the survey results, it is clear that the most important managerial competence is problem solving, both for Polish and foreign managers.

Table 3.
Managerial competencies in the light of research

Managerial competencies	Domestic respondents		Foreign respondents	
	<i>Average</i>	<i>Standard deviation</i>	<i>Average</i>	<i>Standard deviation</i>
Ability to organize time	2,60	8,326664	2,85	6,658328
Balanced thinking	2,80	5,507571	2,85	6,658328
Innovative and adaptive thinking	2,45	7,371115	2,62	4,932883
Collaboration in a virtual environment	2,55	7,371115	2,38	4,50925
Creativity	3,00	11,54701	2,85	6,658328
Troubleshooting	3,00	11,54701	3,00	7,505553
Decision-making	2,10	5,859465	2,62	4,932883
Research skills	2,70	9,073772	3,00	7,505553
Analytical skills	2,60	7,234178	2,54	7,505553
Creating an open environment	3,00	11,54701	2,85	6,658328
Communicate clearly to avoid misunderstandings	2,80	9,865766	2,85	6,658328
Negotiation skills	2,60	8,326664	2,62	4,932883
Ability to delegate authority to employees at lower levels	2,75	8,962886	2,62	4,163332
Posting employees to jobs according to their skills suited to working in the digital economy	2,25	5,507571	2,69	5,859465
Performance orientation	2,70	9,073772	2,77	5,773503
Entrepreneurship	2,80	9,865766	2,77	5,773503

Source: own compilation based on surveys.

In the case of competencies such as performance orientation, entrepreneurship, negotiation skills, communicating clearly to avoid misunderstandings, creating an open environment and, finally, balanced thinking, respondents mostly favored the significant importance of these skills. Differences between domestic and foreign respondents became apparent in the case of competencies such as delegating employees to jobs according to their skills adapted to work in the digital economy, research and decision-making skills. Other competencies were rated relatively well by more than half of the respondents.

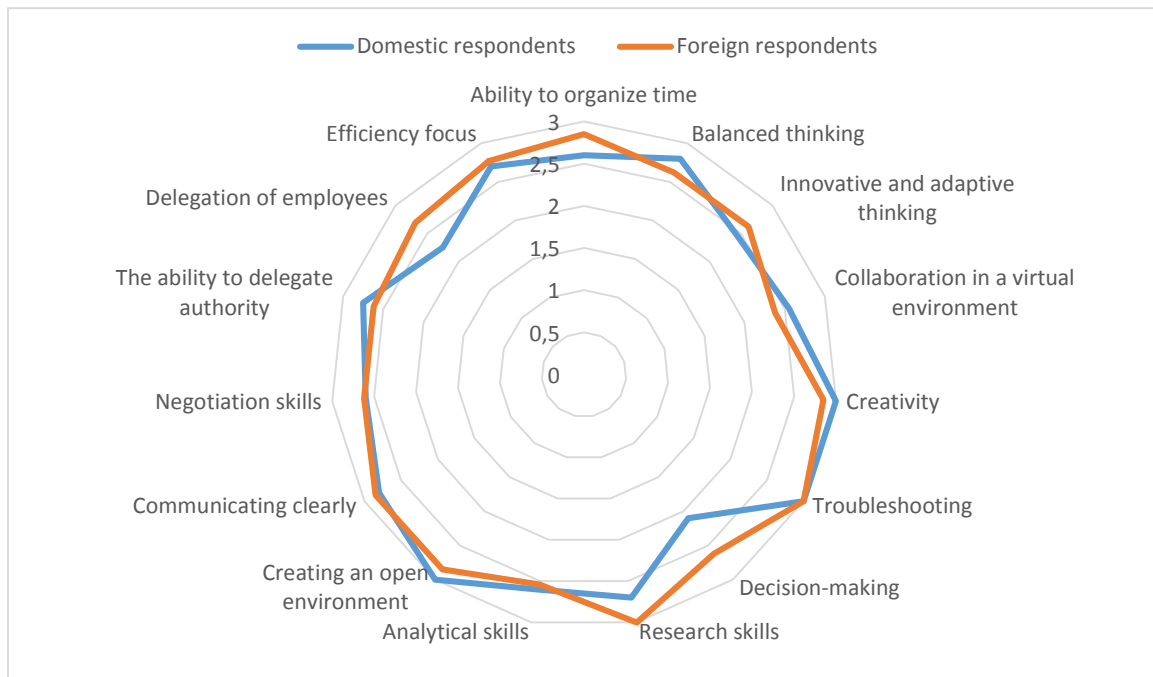


Figure 1. Managerial competencies in the light of surveys.

Source: own elaboration.

Analyzing the results of the standard deviation shows slight differences between the distribution of responses in the Polish and foreign markets. The standard deviation (SD) measures the extent of scattering in a set of values, typically compared to the mean value of the set (Foltynowicz, Łupicka, Jeszka, 2024). Intuitively speaking, the standard deviation tells how widely the values of some quantity are scattered around its mean. The smaller the value of the deviation, the more the observations are clustered around the mean (sustainability, our article). In the case of domestic respondents, the most similar responses were related to three managerial competencies, among others, balanced thinking, decision-making and, finally, posting according to their skills adapted to work in the digital economy. For foreign respondents, it was primarily the ability to delegate authority to employees at lower levels and to collaborate in a virtual environment.

6. Discussion

Technologies such as artificial intelligence, big data, internet of things, blockchain and cyber-physical systems, and topics such as operator 4.0, digital transformation, as well as sustainability and resilience (Madsen et al., 2023) have been identified as the most studied issues related to Industry 5.0. EC documents talking about the transformation of the European economy towards Industry 5.0 emphasize the importance of human capital. Technology is meant to serve people - this human-centric approach is an important difference from the

revolution referred to as Industry 4.0. (European Commission et al., 2021; European Commission. Directorate General for Research and Innovation., 2021) . Industry 5.0 places the welfare of the worker at the center of production processes (Xu et al., 2021).

The most important change in the 5.0 concept from Industry 4.0 is the shift in focus from technology-based advances (IoT, AI, digital twins, robotics, augmented reality) to human-based advances. It is the industry that is to adapt to the needs of the worker, not the human being that is to adapt to the ever-evolving technology (Xu et al., 2021).

This approach has raised the question of whether there will be new challenges in the field of supply chain management and logistics, and what managerial competencies are needed to make the right decisions about the development of organizations and supply chains in the context of the economy's transition towards Industry 5.0.

In the era of Industry 5.0 and widely improved skills related to the economic, social and environmental development of organizations and the emphasis on developing technological and risk management skills, the importance of human collaboration - a key skill in management, including supply chain management - must be restored. Just as important as expertise and process knowledge are specific social, managerial and digital competencies.

Knowledge of currently sought-after competencies, which should be taken into account in the policy of personnel and staff development in various categories gives rise to the demand among employees for training, further education and upgrading of qualifications, the so-called reskilling and upskilling, and Human Resources staffs are faced with this task.

In today's turbulent times, characterized by the constant chase for more and more technological solutions, managerial competencies must be constantly developed.

Leaders and supply chain managers must clearly define each required competency needed to manage teams in digital supply chains. At the same time, they also need to analyze the current owned competencies and skills to identify the gap that needs to be filled to support the digital supply chain vision.

In addition, future tasks and decisions facing managers should be assessed. The most important question should be which activities will remain within the intuition of soft skills of managers, and which should be digitized. Stakeholder relations tasks will certainly remain the responsibility of managers, while, for example, defining supplier selection algorithms will be more automated and supported by technology (Gartner). At the same time, every organization should be oriented towards the development of so-called "open heart competencies", largely concerning emotional intelligence, as no program or application can replace objective assessment of a given situation, which can only be done by a human being. Relating this issue to supply chains, it should be noted that in long-term negotiations, empathy, objectivity counts, and artificial intelligence will not help in this task. The same applies to the evaluation of employees, rigidly written algorithms will indicate positive or negative evaluations and what about the conscientiousness of work even if a given employee is not as efficient as his colleague in the same job? In conclusion, it can be said that in the era of digitization, the idea of Industry

5.0 with its humanocentricity is part of the development of modern supply chains. However, in order to strike a balance between implemented technologies digital technologies and social capital, it is important to acquire managerial competencies to maintain this balance.

7. Applications

Based on the survey, it appears that in the context of continuous and dynamic economic and technological changes, and especially in the context of the transformation towards Industry 5.0, managerial competencies are gaining importance, and these include analytical, interpersonal and strategic skills. Respondents particularly noted and emphasized the relevance in the case of competencies such as problem solving, creativity and sustainable thinking, confirming the growing need for a holistic approach to supply chain management.

Both domestic and foreign respondents noted the need to develop competencies that facilitate functioning in a complex and dynamically changing work environment. Differences between groups of respondents may be due to cultural differences or the level of digital maturity of the organization.

From the perspective of management practice, these results underscore the need to integrate the development of managerial competencies into organizational strategies, especially in highly regulated and technologically advanced sectors such as the medical device industry. At the same time, they point to the importance of synergies between technology and human capital, without which the implementation of Industry 5.0 will not be possible.

It is worth considering additional research in the topics taken up in the article. Interesting conclusions may be provided by cross-industry studies or in-depth qualitative research on competencies of the future. Evaluation of the effectiveness of managerial competence development programs in the context of the transformation towards Industry 5.0 and human-centered economy may also be an interesting direction of analysis.

The results of the study show that there is a need to develop creativity and innovation among management staff, particularly in terms of implementing new technological and organizational solutions. It is equally important to develop sustainable thinking skills through additional training. Preparing managers to identify and reduce the negative impact of supply chain operations on the environment would aim to improve ESG skills and the implementation of the circular economy. The above areas of competence are in line with the objectives of Industry 5.0 and contribute to the creation of future-oriented supply chains.

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DIGITAL TRANSFORMATION OF SMES IN THE VIEW OF DYNAMIC CAPABILITIES – A BIBLIOMETRIC ANALYSIS

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Purpose: The purposes of this article are to: (1) analyze trends in publications related to the digital transformation of SMEs from the optics of dynamic capabilities, (2) identify influential authors, globally cited papers and journals, and notable affiliations related to the research analyzed, (3) explore thematic evolution through a network approach, and (4) determine future research directions in the area of digitization of SMEs from a dynamic capabilities perspective.

Design/methodology/approach: The objectives were achieved using the bibliometric analysis method (RStudio software – Biblioshiny and VOSviewer software). The scientific data consisted of documents exported from the Web of Science database.

Findings: The analysis shows dynamic growth in publications on SME digitization from a dynamic capabilities perspective. It identified leading journals, authors, and affiliations based on article counts and citations. Examining the most cited articles revealed five clusters and their connections, helping to outline future research directions. Additionally, an analysis of frequently occurring words allowed the identification of key themes and four main categories in the literature.

Research limitations: The study relies exclusively on Web of Science data, potentially omitting relevant publications from sources like Scopus or Google Scholar. It uses quantitative analysis without considering content quality or citation context. The bibliometric tools in RStudio are limited in functionality, which may not fully reflect the topic's complexity. Results can also be affected by the chosen time frame and keywords.

Originality/value: This study provides insight into the current state of research in the area of SMEs digitization with the adoption of dynamic capability optics. It contributes to the progress and development of knowledge on this issue by identifying leading trends and research gaps.

Keywords: digital transformation, SMEs, dynamic capabilities.

Category of the paper: Literature review.

1. Introduction

Digital transformation is one of the key factors determining the competitiveness and adaptability of modern enterprises (Gaspar et al., 2024; Ma et al., 2025). In an era of dynamic technological development and changing consumer expectations, the implementation of digital solutions is becoming not only an opportunity for growth, but often a condition for survival in the market (Straub et al., 2021; Sun et al., 2024; Urban, Plattfaut, 2025). This is particularly important in the context of the small and medium-sized enterprise (SME) sector, which - despite limited resources - can, through digitization, improve operational processes, increase efficiency and reach new groups of customers (Silva et al., 2022).

In recent years, there has been growing interest among researchers in the topic of digitization of small and medium-sized enterprises (SMEs), which is reflected in the growing number of scientific publications devoted to this issue (Bilal et al., 2024; Wang et al., 2023; Williams, Schallmo, Lang, Williams et al., 2019). However, despite the increase in research, relatively few authors analyze the digital transformation process from a dynamic capabilities perspective (Fan et al., 2024; Li et al., 2018; Matarazzo et al., 2021; Rupeika-Apoga et al., 2022; Skare et al., 2023). Meanwhile, this approach provides a better understanding of how SMEs identify, adapt and reconfigure their resources in response to the changing technological and market environment (Ogrean, 2025). SMEs often operate under conditions of limited resources, low formalization of processes and greater vulnerability to external disruptions. This is why it is not resources per se, but the ability to dynamically reconfigure them that becomes a key source of competitive advantage (Gyamerah et al., 2025). Moreover, the prism of dynamic capabilities makes it possible to identify different transformation paths - from gradual, iterative changes to radical transformations of the operating model. This enables digital development strategies to be better aligned with individual business circumstances, such as the age of the company, the level of digital competence of employees, organizational culture or access to knowledge and social networks (Jie et al., 2025).

The dynamic capabilities perspective therefore represents an important yet still underdeveloped strand of research that can significantly enrich existing analyses of digitization in the SME sector. It seems reasonable, therefore, to undertake research in this area, but the design of new research requires a detailed recognition of the existing body of work in this area, in order to avoid duplication of research or lack of progress in the ongoing scientific discourses. Accordingly, the purposes of this article are to (1) analyze trends in publications related to the digital transformation of SMEs from the optics of dynamic capabilities, (2) identify influential authors, globally cited papers and journals, and notable affiliations related to the research analyzed, (3) explore thematic evolution through a network approach, and (4) determine future research directions in the area of digitization of SMEs from a dynamic capabilities perspective. These objectives will be achieved using the bibliometric analysis method (RStudio software -

Biblioshiny). This study will identify areas of importance and potential research gaps in the literature, thus contributing to the progress and development of knowledge in the area of digitization of SMEs. Thus, the research aims mentioned above make the current study more profound and applicable.

The article consists of five sections. Section 2 provides the theoretical background and considers leading research in the area of digital transformation of SMEs with the adoption of a dynamic capabilities perspective. Section 3 characterizes the methodology of the research procedure. The results of the study and a discussion of the findings are presented in section 4. The last section of the article summarizes the main cognitive results achieved in the course of the research procedure.

2. Theoretical background

The theme of digital transformation of SMEs is widely explored in the literature (Bilal et al., 2024; Silva et al., 2022; Williams, Schallmo, Lang, Boardman, 2019). A new important and at the same time dynamically developing trend within this issue seems to be the digitization of SMEs from the perspective of dynamic capabilities (Fan et al., 2024; Gyamerah et al., 2025; Hafeez et al., 2025; Jie et al., 2025). Researchers addressing this topic recognize the need to implement new technologies in this category of enterprises while developing dynamic capabilities. An overview of selected studies in this area is presented in Table 1. Analyzing the data in Table 1 with the study context criterion in mind, it can be noted that two studies were conducted in Vietnam, two in China, and one each in Indonesia, Ecuador, Germany/Austria/Switzerland, Italy, Sardinia, and the Czech Republic. Six studies focused on SMEs, one on MSMEs, one on small businesses, one on family-owned SMEs, and one on agrifood SMEs. Some studies included additional sectoral focus (such as manufacturing/service, food/fashion/furniture). Taking into consideration the methodology five studies used quantitative methods, three studies used qualitative methods (including two case studies and three with interviews) and finally two studies used mixed methods (both including SEM and one with Fuzzy-set Qualitative Comparative Analysis). As for the sample size, it ranged from 6 to 596 for firm-level studies, and from 15 to 127 for qualitative interview-based studies. Regarding the thread of key dynamic capabilities that were analyzed in the studies presented, the three studies examined the core dynamic capabilities framework (sensing, seizing, transforming), with one study including all three, one including two, and one including sensing plus learning/integrating/coordinating. Three studies examined digital-specific capabilities, including digital exploitation, digital exploration, digital capability (broadly defined), digital literacy, and security. One study examined human capital, structural social capital, and entrepreneurial competencies. Four studies examined dynamic capabilities in

a more general or unspecified way, including stage specific, not further specified, collaborative/social, or various types.

Table 1.

A review of selected research in the area of SME digitization with the adoption of a dynamic capabilities perspective

Study	Study context	Research Focus	Methodology	Key Dynamic Capabilities Examined
(Vo Thai et al., 2024)	Vietnamese Small and Medium-sized Enterprises (SMEs); emerging market	Relationship between dynamic capabilities, digitalization strategies, business model innovation, and sustainable performance	Quantitative; validated measurement framework; sample size = 596	Sensing, seizing, transforming
(Jing et al., 2023)	Chinese SMEs; accelerating digital transformation	Digital ambidextrous capabilities, business model innovation, transformation performance	Mixed methods; Structural Equation Modeling (SEM), Fuzzy-set Qualitative Comparative Analysis (fsQCA); sample size = 289	Digital exploitation, digital exploration
(Prakasa, Jumani, 2024)	Indonesian small businesses; East Java	Digital capability, digital business transformation, business performance	Quantitative; SEM; sample size = 330	Digital capability (broadly defined)
(Lang et al., 2023)	Vietnamese SMEs; emerging market	Human/structural capital, entrepreneurial competencies, innovativeness, technology adoption, business performance growth	Mixed methods; SEM; sample size = 371	Human capital, structural social capital, entrepreneurial competencies
(Amaya et al., 2024)	Ecuadorian Micro, Small, and Medium-sized Enterprises (MSMEs); developing economy	Dynamic capabilities, digitalization, moderating role of firm age	Quantitative; SEM, Partial Least Squares (PLS), Confirmatory Factor Analysis (CFA); sample size = 280	Sensing, seizing
(Soluk, Kammerlander, 2021)	Family-owned Mittelstand manufacturing SMEs; Germany, Austria, Switzerland	Stages, enablers, and barriers of digital transformation	Qualitative; multiple case study, 127 interviews (15 firms)	Dynamic capabilities (stage-specific)
(Chung et al., 2024)	Chinese SMEs	Digital transformation, customer value creation, dynamic capabilities	Qualitative; multi-case study (6 SMEs), interviews	Sensing, learning, integrating, coordinating

Cont. table 1.

(Matarazzo et al., 2021)	Italian SMEs; food, fashion, furniture	Digital transformation, customer value creation, dynamic capabilities	Qualitative; multi-case study (6 SMEs), interviews	Sensing, learning, integrating, coordinating
(Cannas, 2023)	Sardinian agrifood SMEs	Dynamic capabilities and digital transformation	Qualitative; in-depth interviews (21 respondents)	Dynamic capabilities (collaborative, social)
(Civelek et al., 2023)	Czech SMEs; manufacturing/service	Dynamic capabilities and digital transformation	Quantitative; ordinal logistic regression; sample size = 330	Dynamic capabilities (various), digital literacy, security

Digital transformation in small and medium-sized enterprises relies on the adoption of dynamic capabilities that enable firms to spot opportunities, implement changes, and renew their business models. For example, studies by Vo Thai et al. (2024) and Amaya et al. (2024) describe how sensing capabilities help firms identify digital opportunities while seizing capabilities support product and process digitalization. In Chinese SMEs, Hao Jing et al. (2023) link digital ambidexterity with the ability to innovate business models and improve transformation performance. Other investigations document that transforming, learning, and integrating capabilities—especially in traditional or resource-constrained settings—foster gradual digital advancement, as illustrated by the staged process observed by Soluk and Kammerlander (2021). Organizational factors such as limited resources, firm age, and human or social capital modulate these dynamics. For instance, older firms exhibit reduced responsiveness in sensing digital opportunities (Amaya et al., 2024), and challenges related to digital literacy and cybersecurity appear in some contexts (Civelek et al., 2023). Overall, papers report that the causes of digital transformation lie in the initiation and deployment of diverse dynamic capabilities; the advancement follows a process that ranges from incremental digital adoption to comprehensive business model revision; and the effects include improved operational performance, enhanced customer value, and innovation.

3. Methodology

Bibliometrics is a quantitative method for analyzing scientific data and is an open-source statistical analysis tool for mapping science written in R to measure productivity within a research topic (Aria, Cuccurullo, 2017). The methodology used in the current study involves bibliometric analysis, and the scientific data consists of documents exported from the Web of Science database. The analysis was performed using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) 2020 checklist (Page et al., 2021).

Articles for analysis were obtained by using thematic searches. Search queries in the database included keywords such as: “digital transformation” and ‘SME’ and “dynamic capabilities”. Further analysis was performed on records extracted from the Web of Science database that matched the search terms in title, abstract or keywords.

Data recovered from the Web of Science database on May 20, 2025, yielded 81 documents. In phase one of the research procedure, an initial selection of documents was made by applying two “document types” filters – „article” and “language” - “English” (Table 2). This procedure reduced the number of documents from 81 to 74 articles. In phase two, the remaining articles were manually screened, during which titles, keywords and abstracts were read and analyzed for relevance, thematic adequacy and eligibility for inclusion in the final bibliometric review. Nine articles were considered irrelevant to the issue under consideration (they did not directly relate to the constructs under analysis). After the second selection phase, 65 articles remained and were included in the bibliometric analysis. RStudio software (Biblioshiny) was used for data loading, conversion and bibliometric analysis. It allows extracting and processing complete bibliographic data from an Excel file exported from the Web of Science database. The purpose of using this tool is to review, analyze and provide insight into the current status and future direction of research in the area of small and medium-sized enterprise transformation from the optics of dynamic capabilities. It also allows to statistically assess the scientific quality of journals identifying new thematic trends from this area in 2018-2025.

Table 2.

Inclusion and exclusion criteria

Criteria	Inclusion	Exclusion
Language	English	Other than English
Timeline	2018-2025	Earlier than 2018
Literature	Articles	Other than articles
Subject area	Digital transformation, SME, dynamic capabilities	Other than digital transformation, SME, dynamic capabilities

Table 3 shows detailed data downloaded from the Web of Science database. It includes the timespan of the documents analyzed, the sources from which they came, the number of documents (articles), the annual growth rate (%), document average age, average citations per document. In addition, the content of the documents, including the keywords used by the authors, the percentage of international co-authorships, annual scientific production, globally cited documents, influential authors, affiliations and collective collaborations between countries were obtained using RStudio.

Table 3.*Data extracted form Web of Science database*

MAIN INFORMATION ABOUT DATA	
Timespan	2018-2025
Sources (Journals, Books, etc)	53
Documents	65
Annual Growth Rate %	47.24
Document Average Age	1.74
Average citations per doc	38.43
References	4785
DOCUMENT CONTENTS	
Keywords Plus (ID)	205
Author's Keywords (DE)	247
AUTHORS	
Authors	222
Authors of single-authored docs	1
AUTHORS COLLABORATION	
Single-authored docs	1
Co-Authors per Doc	3.55
International co-authorships %	56.92
DOCUMENT TYPES	
Article	55
article; early access	10

4. The results and discussion

4.1. Publications trends

Based on the acquired data, a steady increase in articles on the issues of digital transformation of small and medium-sized enterprises with the optics of dynamic capabilities can be noted. In the analyzed timespan (2018-2025), a total of 65 articles were published. In 2018-2021 there were single papers, intensive growth occurred from 2022 (11 articles) and remained at a similar level in the following year. The doubling of the number of articles on this issue was observed in 2024 (articles) and this upward trend can be noticed in the current year, where 15 articles were published in the Web of Science database by May 2025.

The dynamic growth in the number of publications on the digital transformation of SMEs from the perspective of dynamic capabilities is mainly due to the increasing importance of technology in business activities and the need for rapid adaptation to market changes, especially after the COVID-19 pandemic (Papadopoulos et al., 2020). Additionally, this topic has gained popularity thanks to political and financial support for digitalization processes and the growing availability of modern technological solutions for SMEs (Côte-Real et al., 2017). The combination of these factors has made this issue a current and important area of scientific research.

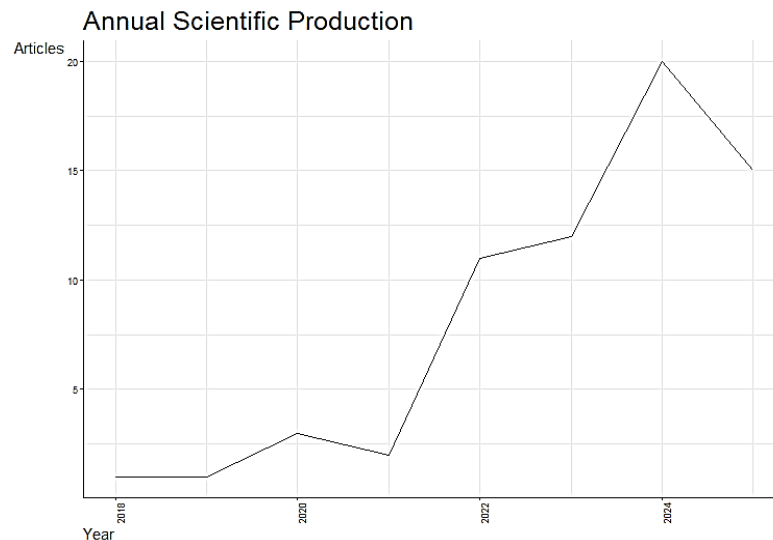


Figure 1. Annual scientific production of articles.

4.2. The most prominent journals on digital transformation of SMEs from the perspective of dynamic capabilities

With the help of RStudio software, it was possible to identify the leading journals publishing research articles on the digitization of SMEs with the adoption of a dynamic capabilities perspective. The top ten of these are shown in Figure 2. Sustainability was ranked first with 5 published articles. This was followed by Journal of Business Research (4 articles), Journal of Enterprise Information Management (3 articles), IEEE Transactions on Engineering Management (2 articles), Small Business Economics (2 articles) and Technological Forecasting and Social Change (2 articles). The remaining 47 articles were published individually in other journals. On the other hand, subjecting the analysis to the journals in which the articles selected from the Web of Science database appeared, with the adoption of the criterion of most local cited sources, it can be seen that the most cited articles were those published in the Journal of Business Research (330 citations).

This was followed by Strategic Management Journal (188 citations), Technological Forecasting and Social Change (164 citations), Sustainability (148 citations) and Long Range Planning (120 citations). The remaining journals among the top ten in terms of citations of articles on SME digitization in terms of dynamic capabilities are presented within Table 4.

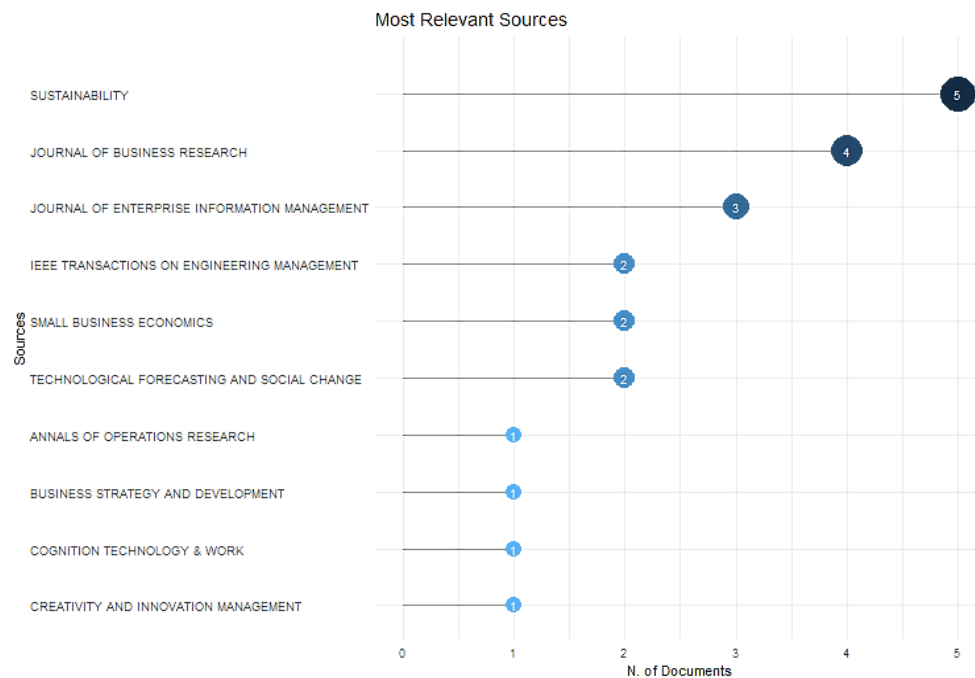


Figure 2. Most relevant sources (number of articles).

Table 4.

Most local cited sources

Sources	Citation
Journal of Business Research	330
Strategic Management Journal	188
Technological Forecasting and Social Change	164
Sustainability	148
Long Range Planning	120
MIS Quarterly	118
Journal of Strategic Information Systems	88
Industrial Marketing Management	77
Technovation	73
Journal of Management	68

The most articles on the digitization of SMEs from the perspective of dynamic capabilities are published in the journal Sustainability, indicating the growing importance of this topic in research on sustainable development. Apart from a few leading journals, most articles (47 out of 65) were published individually in various other journals, indicating a dispersion of research across multiple disciplines. Although Sustainability published the most articles, the most frequently cited papers appeared in the Journal of Business Research, suggesting that citation impact does not always correlate with the number of publications. The Strategic Management Journal and Technological Forecasting and Social Change also ranked high in citation counts, highlighting the interdisciplinary nature of this research area (strategic management, technology forecasting, sustainable development).

4.3. The most prominent authors, publications and affiliations from the analyzed issues

In an effort to identify authors involved in the issue of the digitization process of small and medium-sized enterprises with the adoption of the optics of dynamic capabilities, several criteria can be used to analyze articles extracted from the Web of Science database, i.e. author's production over time, most global cited documents or most relevant affiliations. The results of the analysis with the adoption of the first criterion are presented in Figure 3, where one can see the individual authors along with the number of published articles on the subject under consideration and the number of citations per year. It can be noted that two authors have published 2 articles each in the period 2018-2025, they are: Alarifi Ghadah and Satar Mir Shahid. Taking the number of citations per year as a criterion, four authors obtained a number of citations between 13 and 17, they are: Sohu Jan Muhammad, Akhtar Sadaf, Bilal Muhammad and Aagaard Annabeth. Figure 4 shows the articles with the adoption of the criterion of most global cited documents. It can be noticed that two articles with the number of citations above 500 cites come to the front, i.e. (Matarazzo et al., 2021) (article published in Journal of Business Research) and (Li et al., 2018) (article published in Information Systems). Other authors with the most citations are presented within the framework of Figure 4. Analyzing the affiliation of authors addressing the issue of SME transformation in terms of dynamic capabilities, it is noted that the leading center with the number of 5 thematic articles is Universitat Siegen (Germany). In second place with 4 articles were 3 affiliations, namely: Jiangsu University (China), University of Deusto (Spain) and Vietnam National University, Ho Chi Minh City (Vietnam). In third place (three articles) were two research centers, namely University of Vaasa (Finland) and Vnu-Hcm International University (Vietnam) (Table 5).

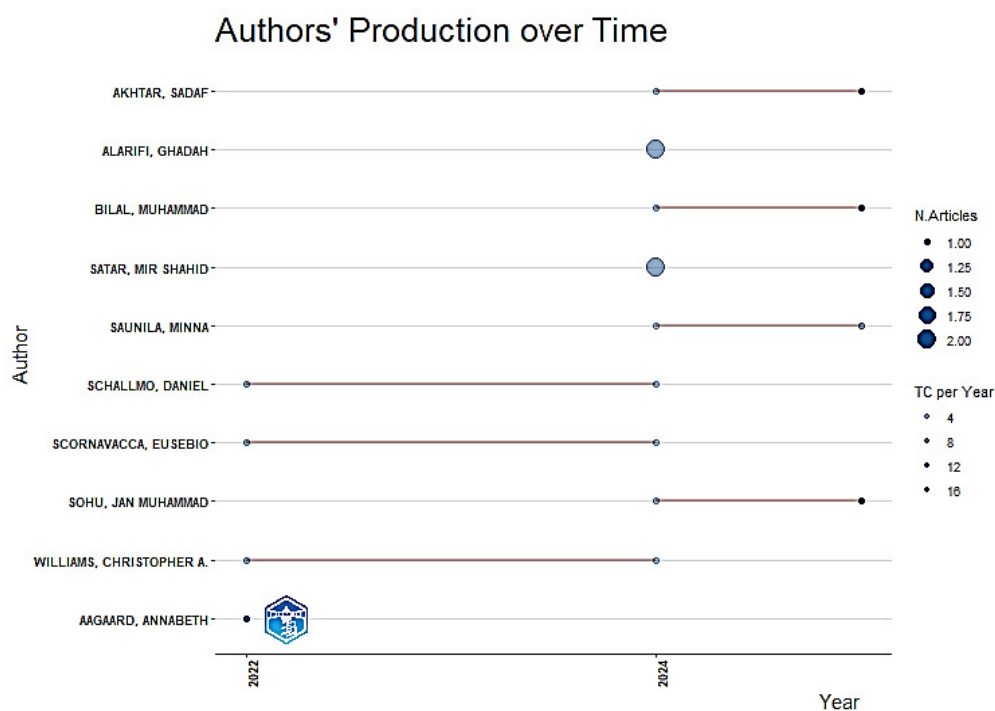


Figure 3. Author's production over time including number of articles and citation counts per year).

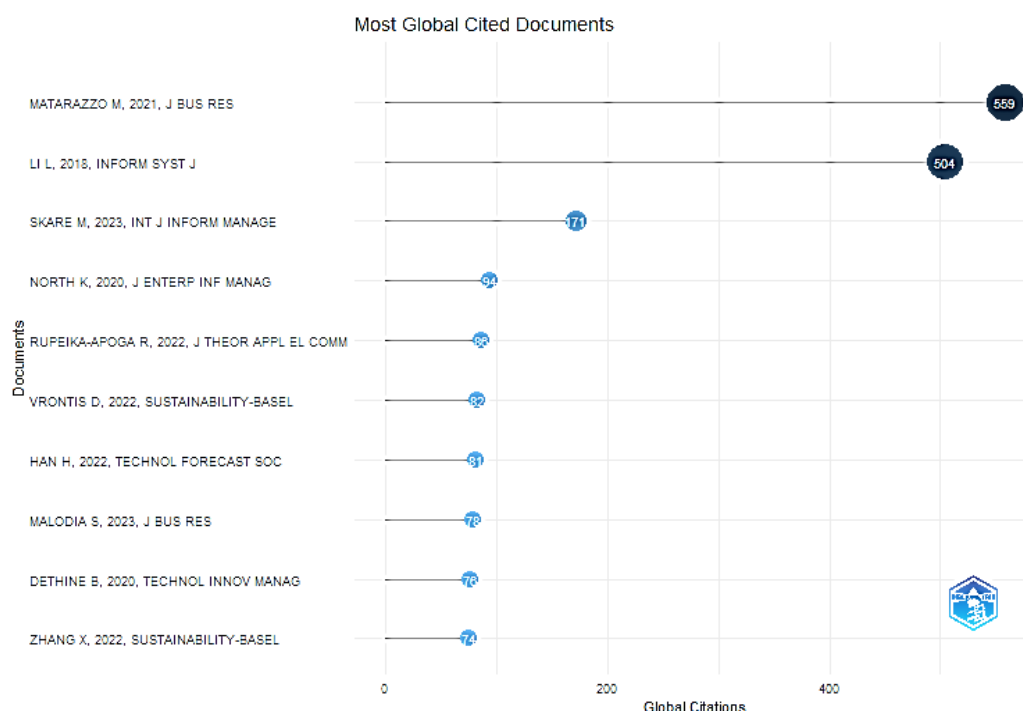


Figure 4. Most global cited documents.

Analysis of the most frequently cited articles downloaded from the Web of Science database made it possible to identify clusters and their relationships. VOSviewer software, which is a software tool for constructing and visualizing bibliometric networks, was used to identify clusters. The network includes individual publications and it was constructed based on bibliographic coupling. The analysis carried out showed, the existence of five clusters centered around the articles with the highest representativeness (having the greatest links to references of other articles - Figure 5), among them are: (1) (Matarazzo et al., 2021; Li et al., 2018; Skare et al., 2023; North et al., 2020) and (Rupeika-Apoga et al., 2022), which is consistent with the results of the analysis considering most global cited documents.

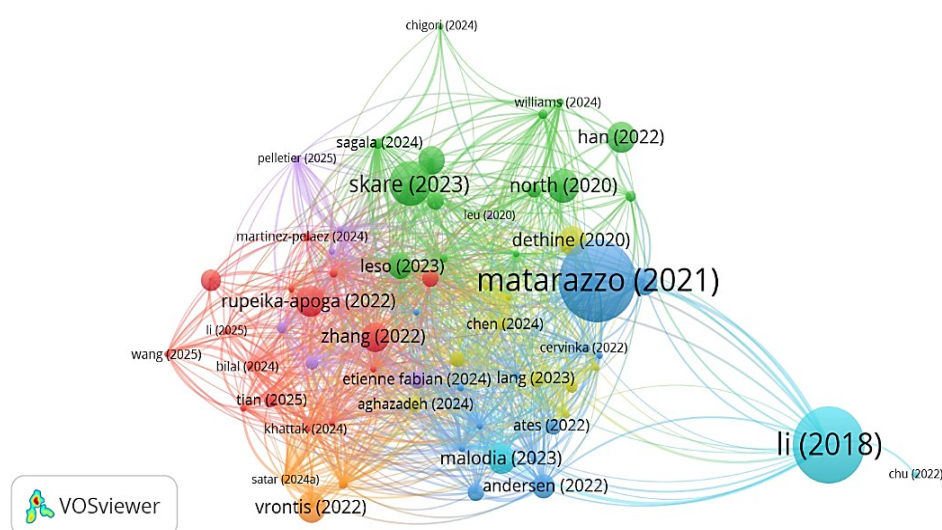


Figure 5. Analysis of the most relevant clusters of thematic publications.

Table 5.*Most relevant affiliations*

Affiliation	Articles
UNIVERSITÄT SIEGEN	5
JIANGSU UNIVERSITY	4
UNIVERSITY OF DEUSTO	4
VIETNAM NATIONAL UNIVERSITY HO CHI MINH CITY (VNUHCM) SYSTEM	4
UNIVERSITY OF VAASA	3
VNU-HCM INTERNATIONAL UNIVERSITY (VNUHCM-IU)	3
ARIZONA STATE UNIVERSITY	2
ARIZONA STATE UNIVERSITY-TEMPE	2
ESIC	2

4.4. Analysis of high-frequency words

The bibliometric analysis conducted made it possible to identify the most relevant words appearing in the collected articles (Table 6). The leading term was “digital transformation”, followed by the construct referring to the subject of the research, namely „smes” or “sme”. The research optics adopted also turned out to be an important word; the analyzed articles were prepared with the adoption of a “dynamic capabilities” perspective. This was followed by a word related to “digital transformation”, that is, “digitalization”. The articles also included theoretical constructs resulting from the transformation process, namely “innovation”, „performance” or “competitive advantage”. The analyzed studies were also conducted in relation to the concept of “industry 4.0” or with the inclusion of “digital capability” as a special type of dynamic capabilities. A graphical representation of the most relevant words in the analyzed publications is shown in Figure 6.

Table 6.*Most relevant words*

Words	Occurrences
digital transformation	38
SMEs	18
dynamic capabilities	13
SME	13
digitalization	8
innovation	5
performance	5
competitive advantage	4
digital capability	4
industry 4	4

**Figure 6.** WordCloud.

RStudio software also makes it possible to analyze the frequency of keywords over the analyzed years (Figure 7). It can be observed that the frequency of all words classified as relevant increases over the analyzed period. The largest increase in frequency can be observed for the construct “digital transformation” starting in 2021 and ‘smes’/“sme” also starting in the same year.

The term "digital transformation" plays a central role as the most frequently appearing keyword, confirming it as the main topic of the analyzed articles. There is a clear focus on SMEs and the dynamic capabilities perspective, as evidenced by the frequent occurrence of the terms "SMEs" and "dynamic capabilities", highlighting a strong connection between the research topics and this group of enterprises along with a specific theoretical approach. Additionally, concepts related to transformation—such as "digitalization", "innovation", "performance", and "competitive advantage"—underscore the complexity of the digital transformation process and its impact on firm outcomes and competitive advantages. The inclusion of terms like "Industry 4.0" and "digital capability" reflects an expansion of the topic to incorporate new technologies and specific digital competencies as integral elements of dynamic capabilities. Overall, the diverse set of key terms demonstrates the interdisciplinary nature of the research, combining management, technology, and innovation.

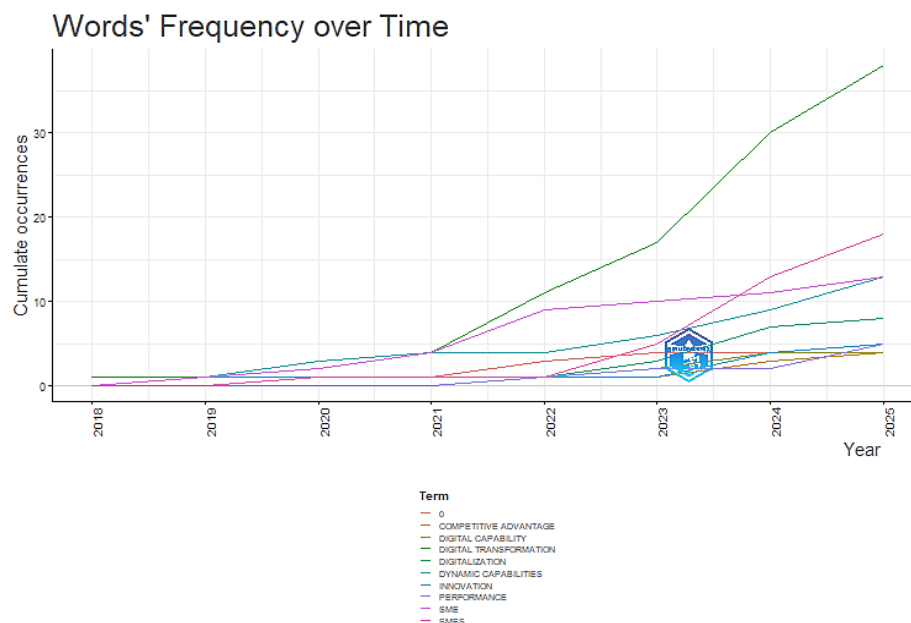


Figure 7. Words' frequency over time.

The analysis of high-frequency words and their co-occurrence also makes it possible to determine four categories of themes addressed by researchers: niche themes (low degree of relevance and high degree of development), motor themes (high degree of relevance and high degree of development), emerging or declining themes (low degree of relevance and low degree of development), and basic themes (high degree of relevance and low degree of development). The graphical presentation of the identified topics is presented in Figure 8. The bibliometric analysis carried out confirms that the issue of digitization of small and medium-sized

enterprises from the perspective of dynamic capabilities is a significant and intensively developing research area (motor themes), compared to the general issue of digitization of small and medium-sized enterprises, which falls into the category of basic themes characterized by low relevance and development. Thus, it seems that the factor that makes the research issue attractive is the adoption of the optics of dynamic capabilities in relation to the transformation process of SMEs. Slightly less relevant, but relatively strongly developing, is the issue of dynamic capabilities and their impact on achieving competitive advantage in relation to incumbent firms. A niche but intensely developing theme is that related to the concept of Industry 4.0 and collaboration. Emerging theme seems to be the topic of talent management conducted in relation to small and medium-sized enterprises.

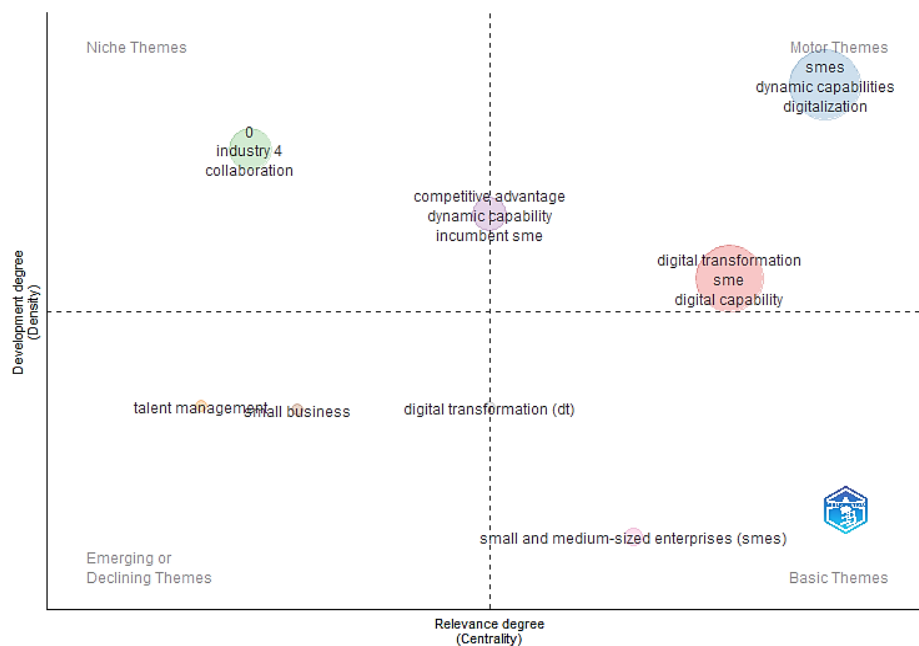


Figure 8. Categories of themes in analyzed articles.

The analysis identified four categories of research themes in the study of SME digitization from the perspective of dynamic capabilities: niche themes, motor themes, emerging or declining themes, and basic themes, reflecting varying degrees of relevance and development. Notably, the digitization of SMEs through the lens of dynamic capabilities stands out as a highly relevant and well-developed area, indicating that adopting this perspective significantly enhances the attractiveness and growth of research in this field. In contrast, more general topics on SME digitization without the dynamic capabilities focus remain less developed and less relevant, highlighting a need for further exploration. Additionally, research on the impact of dynamic capabilities on achieving competitive advantage among incumbent firms is relatively well-developed, though slightly less prominent. Emerging and niche themes such as Industry 4.0, collaboration, and talent management in SMEs suggest new directions and opportunities for future studies.

Adopting the dynamic capabilities perspective significantly increases both the maturity and the visibility of research on SME digitization. This indicates that combining dynamic capabilities theory with studies on digital transformation makes a unique contribution and creates a clearly distinct research stream. General research on SME digitization—without considering dynamic capabilities—remains less developed and less prominent in the academic debate. This may indicate that more in-depth studies are needed on the fundamental aspects of digital transformation that go beyond the dynamic capabilities perspective. Topics such as Industry 4.0, collaboration, and talent management are beginning to attract research interest and represent potentially promising directions for the development of the literature. This reflects the growing importance of integrating advanced technologies and human capital management in the digital transformation of SMEs. The classification of topics into different categories of development and relevance reflects the multidimensional nature of research that combines strategic management, innovation, technology, and organizational capabilities. This highlights the need for interdisciplinary collaboration in building knowledge in this field. The results suggest that further progress in research on SME digitization requires integrating the dynamic capabilities approach with the analysis of technological factors (e.g., Industry 4.0) and social factors (e.g., digital competencies, talent management) in order to capture the full complexity of this transformation process.

4.5. Future research directions

Based on a detailed analysis of the articles qualified by bibliometric analysis as the most prominent, being the center of the identified clusters, it was possible to determine future research directions. These articles highlight various limitations and future research directions that can enhance the understanding of the impact of digital technologies on SMEs in different sectors and business sizes. Suggested research directions include (Dethine et al., 2020; Li et al., 2018; Matarazzo et al., 2021; Rupeika-Apoga et al., 2022; Skare et al., 2023): (1) focusing on specific digital technology instruments such as Cloud Computing (CC), Enterprise Resource Planning (ERP), Customer Relationship Management (CRM), big data and advanced cloud computing, (2) studying the impact of these technologies on companies of different sizes and sectors (this can provide deeper insights into their effectiveness and application), (3) using more comprehensive data sources, such as the Orbis database, to increase the reliability of the results, (4) applying advanced scientific methodologies, such as dynamic panel analysis with time series data, can provide more nuanced insights into how digital technology affects SMEs over time and help understand the longitudinal impact of digital transformation on business operations and performance), (5) developing a global cross-country digital transformation model that examines the impact of digital technology on SMEs around the world, (6) incorporating company-level and industry-level indicators to more accurately assess the impact of digital technology adoption on SMEs.

In summary, the future of digital transformation research in SMEs with the adoption of dynamic capability optics should focus on specific technologies, address data limitations, use advanced methodologies, and incorporate global perspectives. In this way, researchers can contribute to a more comprehensive understanding of how digital technologies can improve the performance and resilience of SMEs in an increasingly digital economy.

5. Conclusions

Analyzing the digital transformation of small and medium-sized enterprises (SMEs) through the lens of dynamic capabilities makes it possible to grasp the “internal logic of change” - that is, the deep mechanisms that allow companies not only to survive under growing technological uncertainty, but also to actively adapt and grow. Instead of treating digitization as a one-time deployment of new IT tools, the dynamic capabilities approach makes it possible to understand digital transformation as a process of strategic learning and continuous adaptation to a changing environment. Therefore, it seems justified to undertake research in this area, but it should be preceded by a thorough analysis of the previous achievements of researchers in this area. This can be done using the method of bibliometric analysis. This study covers the analysis of articles from 2018-2025, providing a comprehensive overview of research on the issue of digitization of small and medium-sized enterprises with the concept of dynamic capabilities. The results of the analysis conducted show dynamic growth based on the annual production of articles in this area. It can be noted that in 2018 the research on the issue of digitization of SMEs in terms of dynamic capabilities was at an early stage, but gained momentum in 2020, resulting in a rapid increase in articles in 2024. The intensification of research in this area demonstrates the interest of researchers in this field. A comprehensive analysis made it possible to identify prominent journals, both in terms of the number of topical articles (Sustainability, Journal of Enterprise Information Management) and the number of citations (Journal of Business Research, Strategic Management Journal, Technological Forecasting and Social Change). Leading authors were also identified by taking author's production over time (Alarifi Ghadah and Satar Mir Shahid), number of citations per year (Sohu Jan Muhammad, Akhtar Sadaf, Bilal Muhammad and Aagaard Annabeth) and most globally cited documents (Matarazzo et al., 2021) - article published in Journal of Business Research and (Li et al., 2018) - article published in Information Systems Journal) as criteria. Analysis of the most cited articles in the pool of articles obtained from the Web of Science database made it possible to identify clusters and links between them. Based on a thorough analysis of the most important articles from each cluster, the main directions for future research were determined.

The analysis also identified the most important affiliations - centers where research in this area is conducted (Universitat Siegen - Germany; Jiangsu University - China), University of Deusto - Spain and Vietnam National University, Ho Chi Minh City - Vietnam). In addition, analysis of high-frequency words and their co-occurrences made it possible to identify the most relevant words appearing in the set of analyzed articles and their frequency of occurrence. This, in turn, made it possible to identify four categories of themes appearing in articles on this subject. The bibliometric analysis conducted confirms that the issue of digitization of small and medium-sized enterprises from the perspective of dynamic capabilities is the so-called “motor theme”, compared to the general issue of digitization of small and medium-sized enterprises, which can be categorized as basic themes characterized by low relevance and development. It can be assumed that the factor that fosters the increase in relevance and development of this theme is the combination of the constructs of digital transformation and dynamic capabilities in relation to the SME category.

On the basis of the bibliometric analysis conducted, an attempt can be made to formulate both theoretical and empirical implications. The study confirms the growing interest and dynamic development of the topic of SME digitization from the perspective of dynamic capabilities, indicating the need for further deepening of knowledge combining these two areas. The identification of key articles, authors, and research institutions allows for a better understanding of the main trends and thematic connections in the literature, facilitating the development of coherent and comprehensive theoretical models. Highlighting the role of dynamic capabilities as a “motor theme” suggests that integrating the concepts of digital transformation with dynamic capabilities theory may be crucial for future research on SME innovation and adaptation.

The rapid increase in publications and interest in the topic indicates the growing importance of SME digital transformation for business practitioners. Knowledge about leading institutions and authors can help companies and decision-makers establish industry-academic collaborations and leverage the latest research achievements. Understanding key themes and their development helps practitioners identify areas that require investment and innovation, particularly in building organizational dynamic capabilities that support effective digital transformation and competitive advantage for SMEs.

This study, based on a bibliometric analysis conducted using the RStudio environment, involves several important limitations. First and foremost, it relies solely on data from the Web of Science database, which may lead to the omission of relevant publications available in other sources, such as Scopus or Google Scholar. The study does not account for potential language and regional biases in the dataset, which may disproportionately reflect English-language or Western-centric publications, limiting the global representativeness of the findings. The analysis is quantitative in nature and therefore does not account for the quality of content or the context of citations. Additionally, the scope of the analysis was limited by the capabilities of the Biblioshiny package and the quality of the metadata, which may contain errors or

inconsistencies. The results may also be influenced by the selected time frame and the choice of keywords.

Despite the above limitations, this study provides insight into the current state of research in the area of SME digitization with the adoption of dynamic capability optics. It contributes to the progress and development of knowledge on this issue by identifying leading trends and research gaps.

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ASSESSMENT OF BIOLOGICAL HAZARDS IN THE MINING ENVIRONMENT ON THE EXAMPLE OF THE PREPARATORY WORKS DIVISION

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Purpose: The presented article is empirical in nature and deals with the proposal of biological risk assessment in the mining work environment in connection with the imposition by the Parliament of the European Union and the Polish Ministry of Health on employers of this assessment also in the face of unintentional biological factors accompanying business activities. Its purpose is to draw the attention of the management of coal mines in Poland to the biological hazards accompanying the technological processes associated with coal mining, which may have an impact on the deterioration of the health of mining crews, and the obligations that fall on the employer and occupational health and safety services in connection with the need to comply with the provisions of Article 207 of the Labour Code (Labour Code) and the changing European legislation (Directive of the Commission (EU): 2019/1833 of October 24, 2019 and 2020/739 of June 3, 2020) as implemented into the Polish regulatory framework (Regulation of the Minister of Health of December 11, 2020 - Dz.U. 2020 item 2234).

Design/methodology/approach: The risk assessment of biological hazards accompanying the technological process in mining conditions in the preparatory works division of a coal mine was carried out based on the assumptions of the descriptive method of occupational risk assessment according to the guidelines of the Institute of Occupational Medicine in Lodz (Kozajda, Miśkiewicz, 2022). To identify biological hazards in the mining work environment, a group of available research methods was used based on: interview, site visit combined with environmental and laboratory tests, and analysis of available literature on biological hazards.

Findings: The study showed that there are many more biological hazards accompanying the coal mining process in the mining environment than the mine health and safety services had previously assumed. The increase in biohazards increases with the depth of mining and the deterioration of working climatic conditions. In the mining environment there are also biological factors classified as group 3 human hazard, which could not be detected by the procedures used by mines to identify biological hazards and quantitative methods of occupational risk assessment. It is therefore advisable to implement new solutions and research methods described in the article that allow to increase the safety of miners' work in terms of biological hazards.

Research limitations/implications: Harmful factors present in the mining work environment that can affect the health of coal mine workers hard coal is a sensitive issue and one that is reluctantly raised by mine management, union organizations and the workers themselves. Miners hide their ailments for fear of losing their jobs and are reluctant to undergo diagnostic tests. Therefore, a condition of conducting environmental studies at the mine in question and

compiling data for the purposes of the above article was to guarantee the complete anonymity of the subjects and the workplace. The obligation to protect the source of the data stems from Order No. 54/2022 of the Rector of the Silesian University of Technology dated March 1, 2022 on the introduction of the Book of the Educational Quality Assurance System (Legal Monitor of the Silesian University of Technology, 2022, item 154) and the cooperation agreements between the Silesian University of Technology and individual business entities.

Practical implications: The descriptive method of risk assessment for biological hazards in the mining work environment presented in the article can be directly implied for practical use not only by the health and safety services of mines and mining plants, but also by the health and safety services of other business entities.

Social implications: Biological agents found in the work environment are a growing social problem. Its effect is an increase in the number of workers exposed to biological agents also in branches of the national economy in which they have not previously been identified. This phenomenon raises the social costs associated with the loss of working capacity of an increasing number of workers diagnosed with occupational diseases of biological origin and the need to treat those infected. A proper procedure for identifying and assessing biological hazards in the work environment can reduce this phenomenon by indicating more effective prophylaxis against biological agents in workplaces.

Originality/value: The article is directed to the management of coal mines and occupational health and safety services, to whom it points out the places of possible occurrence of biological hazards in the mining environment, as well as ways of assessing these hazards and directions for taking more effective preventive measures to reduce health risks for miners.

Keywords: mine, preparatory works department, biological hazards, risk assessment, preventive measures.

Category of the paper: Original work (scientific - research).

1. Introduction

Biological hazards, although often associated primarily with medicine, diagnostic laboratories, the food industry, agriculture, animal husbandry or waste management, are also found in many other work environments that at first glance are not directly associated with biological hazards. Their presence may not be obvious, and yet pose a real risk of infections, allergies or other occupational diseases. Therefore, according to the new guidelines contained in the Decree of the Minister of Health of December 11, 2020. - OJ. 2020 item 2234 (ISAP 2020), every employer is required to update the assessment of occupational risks to which an employee is or may be exposed, even if biological risks are not due to the nature of the work itself, but may be present in the work environment incidentally or unintentionally.

The indicated regulation, following the position of the European Commission in Directives: 2019/1833 and 2020/739 (EUR-lex 2019, 2020) updated not only the list of biological agents and the list of work exposed to them, but also strengthened the obligation to assess biological risks in a comprehensive manner. According to §6(1) of the regulation: "The employer, taking into account the type, degree and duration of the employee's exposure to biological agents and

the risks to health or life, shall assess the occupational risks associated with the employee's exposure to these agents".

These regulations are not limited only to jobs where biological agents are recognizable and identified, but also include all workplaces where there is a possibility of their presence, even if they are not part of the basic technological process.

Examples of non-obvious jobs where biological risks due to working conditions, environment or auxiliary materials should be assessed include:

1. Work in the construction industry - when working in old buildings, contact with mold (e.g., *Aspergillus*, *Penicillium*), soil bacteria or animal feces (e.g., pigeons) can occur, which are sources of respiratory infections or zoonoses.
2. Work in the wood and paper industry - when handling organic raw materials in a soggy environment, there is a risk of exposure to fungal toxins (mycotoxins) and microorganisms that develop in cellulosic materials.
3. Storage and transportation work - organic products (e.g., grains, wood, foodstuffs) can biodegrade under conditions of improper storage, becoming a source of bacterial and fungal growth.
4. Office work in soggy or poorly ventilated buildings (so-called sick building syndrome) - possible presence of *Legionella pneumophila* bacteria in air conditioning and fungi that cause allergic reactions.
5. Work in the mining and quarrying industry-where there are, among other things, fecal bacteria (e.g., *E. coli*, *Salmonella*), viruses and parasites residing in contaminated mine waters, or ubiquitous molds and fungi (e.g., *Aspergillus*) developing in ventilation ducts or on wooden parts of the mining casing.

The amendment to the regulations on harmful biological agents, introduced in 2020, has already been reflected in the statistics of the Central Statistical Office (Auksztol et al., 2024), which noted a recent jump in the number of people exposed to biological agents in mining from 2 forfeitures in 2019 to 1,064 in 2023, ranking this industry of the economy in 6th place in terms of the number of people employed in conditions threatened by biological agents (Table 1).

The threat of non-obvious biological factors accompanying the mining process in mining, as indicated by the inspection of inspectors of the State Sanitary Inspectorate carried out at some coal mines, may be even greater, as there is still insufficient knowledge and awareness among employers, health and safety services, trade union organizations and workers themselves about potential exposure to biological factors in the workplace and related health problems. The inspectors of the State Sanitary Inspectorate also point out that the occupational health and safety services of coal mines have problems with the identification of biological hazards and their assessment, for in estimating occupational risks they use quantitative methods which, in the absence of hygienic standards for individual groups of biological hazards and their non-

specific effects on workers, often give false results. It is therefore advisable to look for new methods of assessing biological risks and their identification, which is the subject of this paper.

Table 1.

Employed in conditions of risk of biological agents by section in 2019-2023

Section of economic activity PKD	2019	2020	2021	2022	2023
Health care and social assistance	3811	7396	10786	9859	5792
Industry	4672	3292	2727	4341	4687
• Water supply; sewage and waste management; reclamation	2485	2283	1544	2953	2283
• industrial processing	1991	992	965	1274	1261
• mining and quarrying	2	6	154	54	1064
• generation and supply of electricity, gas, steam and hot water	194	11	63	60	79
Agriculture, forestry, hunting and fishing	1422	1673	1874	1619	1153
Trade; repair of motor vehicles	263	601	278	746	204
Construction	314	265	477	449	679
Transport and warehouse management	82	156	100	305	186
Professional, scientific and technical activities	24	100	76	152	102
Education	52	176	331	28	31

Source: own compilation based on CSO (Auksztol et al., 2024).

2. Assessment of biological risks in the workplace

Biological risks in the work environment have been the subject of many foreign studies for years (Alter et al., 2007; Eduard, 2009; Fromme et al., 2016; Green, Beezhold, 2011; Montano, 2014; Rim, Lim, 2014; Tiong, 2021) and Polish scientists (Dutkiewicz et al., 2011, 2015, 2016; Wójcik-Fatla et al., 2020, 2022; Zukiewicz-Sobczak et al., 2013, 2013a), government agencies such as the European Agency for Safety and Health at Work (EU-OSHA 2009, 2017, 2018, 2019, 2019a, 2019b, 2019c), the National Institute for Occupational Safety and Health, USA (NIOSH 2020) and international organizations among which the largest is the World Health Organization (WHO, 2014, 2018). These studies show that biological factors not only in the work environment, but also in everyday life, have a significant impact on the health of workers and public health more broadly. According to the latest data, it is estimated that around 320000 workers worldwide die annually from work-related infectious diseases, about 5000 of them in the European Union countries (EU-OSHA 2020), and more than a billion people worldwide are exposed to them on a daily basis. Statistical data on occupational morbidity in individual countries of Europe and the world as well as ongoing scientific research (Szymanska, 2007, Fijan, Šostar Turk, 2012; Dulong et al., 2015, Shereen et al., 2020, EU-OSHA, 2019c) indicate that health care workers are among the most vulnerable occupational groups. In this group, the most common risks are bloodborne infections such as HIV, hepatitis B and C, as well as tuberculosis and influenza. Infections mainly occur through needlestick injuries or contact with infected biological material. These risks affect doctors and nurses as well as support staff, such as cleaners and temporary workers, who are often not properly trained and equipped with

personal protective equipment. Biological hazards, however, as research shows, are not just the domain of one occupational group. Biological agents also cause occupational diseases among farmers (Spankie, Cherrie, 2012; Pearson et al., 2015; Cano-Jiménez et al., 2016; Schlosser et al., 2018; EU-OSHA, 2019a), waste and wastewater workers (Kuijjer, Sluiter, 2010; Anzivino-Viricel et al., 2012; Duquenne et al., 2014), animal professionals: veterinarians, abattoir, slaughterhouse, laboratory or animal husbandry workers (Yilmaz et al., 2013; Feary, Cullinan, 2016; Zamfir et al., 2019). In the scientific databases Web of science, Scopus, MDPI, Google Scholar, CrossRef, there are also many comprehensive studies on biological hazards in the work environment and their impact on the health of workers also in other occupational groups in which biological exposure is not as obvious as in the occupations mentioned earlier (Liebers et al., 2007; Dutkiewicz, 2011; Duquenne et al., 2013; Walser et al., 2015; EU-OSHA, 2017, 2020f). All of these studies clearly indicate that biological hazards are today a growing challenge for employers and occupational health and safety services in their identification, risk assessment and planned preventive measures. A limitation in this regard pointed out by many experts (Brun, Milczarek, Roskams, 2007; Crook, 2007; Eduard et al., 2012; Carducci et al., 2013; Burzoni et al., 2020) is the lack of uniform, widely accepted assessment standards.

Workplace biological risk assessment is a key element in ensuring the health of workers in the face of rapidly changing biological hazards. Despite the growing importance of this field, the process of biological risk assessment is fraught with numerous methodological, organizational and cognitive difficulties. As pointed out as early as the late 1990s (Seedorf et al., 1998), the diversity of biological factors and the lack of standardized measurement methods hinder the comparability of data across sectors. Qualitative approaches dominate over quantitative ones (Douwes et al., 2003), which in practice results in a high dependence of results on subjective assessments by experts. In addition, biological agents, i.e. viruses, fungi parasites, can be present in the environment as well as generated as part of industrial processes (Burzoni et al., 2020) which makes a real risk assessment require taking into account not only the presence of the agent, but also its infectious dose, stability in the environment and routes of transmission - a point supported by the work of (Crook, Burton 2010), who point to the need to integrate microbiological data with exposure assessment. Crook, in his publications discussing problems with biological risk assessment, also points to insufficient epidemiological data and the lack of clear exposure standards for many pathogens. On the other hand (Eduard et al., 2012), points out that measuring actual worker exposure (exposure) is a challenge when assessing biological risk, as exposure factors are often aerosol in nature and difficult to detect using traditional environmental monitoring methods. Moreover, measuring the presence of microorganisms does not always correlate with the risk of infection - exposure assessment models based on epidemiological and toxicological data are therefore needed (Schlosser et al., 2009).

As a result of the difficulties identified, the concept of Quantitative Microbial Risk Assessment (QMRA) is increasingly emerging in the literature. Rose et al. (2013) present QMRA as an approach involving four main steps: hazard identification, exposure assessment, dose-response assessment, and risk characterization. This structure allows for a more precise prediction of health effects resulting from exposure to a specific biological agent. For example, Carducci et al. (2016) used the QMRA method to assess the risk of adenovirus infection in water and wastewater management facilities. The analysis made it possible to estimate the probability of infection depending on the type of work performed and the personal protective equipment used. Similarly, Paccha et al. (2016) modeled the risk of zoonotic influenza infection among swine farm workers. Burzoni et al. (2020) in their publications proposed a model for a comprehensive approach to biological risk assessment that integrates hazard identification, exposure assessment, health effects analysis and implementation of control measures. These assumptions coincide with the guidelines of the Institute of Occupational Medicine in Lodz (Kozajda, Miśkiewicz, 2022) on occupational risk assessment of harmful biological agents consisting in replacing the method of occupational risk assessment presented in the Polish Standard PN-N-18002 (PKN 2011), which is commonly used by workplaces in Poland, with a descriptive method involving the collection of all relevant information about the work environment, identification of biological factors posing a risk at individual workplaces, identification of the highest risk group among the biological factors present or potentially present, and proposing on this basis the most effective set of risk-reducing preventive measures.

The discussion presented above shows that the assessment of biological risks in the work environment, as opposed to measurable factors, is a complex process, which is influenced not only by the biological conditions of the work environment, the individual personal sensitivity of employees, but also by the current legal requirements of the country and safety culture. Therefore, employers and occupational health and safety services concerned about the safety of their employees should focus not only on developing effective tools for risk assessment, but also on educating employees and the professional community about risks and health policies, because only in this way can biological factors present in the work environment be effectively countered.

3. Research methodology

Coal mines are working environments with a higher degree of risk, not only natural, physical, chemical or mechanical, but also biological. However, biological risks in modern mines compared to other obvious mining hazards as a side element of the main technological process associated with mining have been underestimated by employers and health and safety services. Meanwhile, as the examples of other industries presented in Chapter 2 of this paper

show, it can be an important element affecting the health of workers and the operation of mining facilities. Thus, the assessment of biological risks in coal mines in Poland required a comprehensive approach that takes into account the specifics of underground work, a humid and warm environment, limited ventilation, contact with mine waters and also contact with a crew of several thousand people, who may be carriers of various disease phenomena.

The quantitative methods of assessing harmful factors used so far are based on the Polish Standard PN-N-18002:2011 (PKN 2011) in which risk (R) is defined as a function of the probability of occurrence of an event (P) and its potential effects (S) related to the value of exceeding the norm of a given harmful factor (formula 1):

$$R = f(P, S) \quad (1)$$

and the Risk Score method (Krause, 2011) in which the risk (R) is determined as the product of the probability of activation of the hazard (P), exposure to the hazard (E) and the probable effects of the hazard (S), expressed by formula (2) prove to be unsuitable in the case of biological agents that do not have hygienic norms and reproducible limit values. As a result, the health and safety services of the mine under investigation were not able to conduct a proper assessment of biological risks and identify all relevant biological agents at workplaces, which was emphasized in their post- inspection reports by the inspectors of the State Sanitary Inspectorate who inspected the mine.

$$R = P \times E \times S \quad (2)$$

Therefore, a qualitative (descriptive) method adapted to non-standard exposure conditions based on the guidelines of the Institute of Occupational Medicine in Lodz (Kozajda, Miśkiewicz, 2022) was used for practical assessment of biological risks in the preparatory works department of the coal mine under study, the course and result of which are presented below in the diagram shown as Figure 1.

3.1. Workplace characterization and identification of potential sources of pathogens

Characterization of the workplace consisted of conducting a site visit and collecting information from the mine's technical and health and safety services about:

1. The location of the selected mine division (explant or excavation site, mining level, type of mining deposit).
2. Environmental parameters:
 - humidity and air temperature (measured with hygrometers and Assman PM-8211 Psychrometer).
 - Air velocity and direction (anemometers) - influence on the spread of suspended particles.
 - Natural and technical hazards (especially machinery and equipment used ways to monitor hazards).

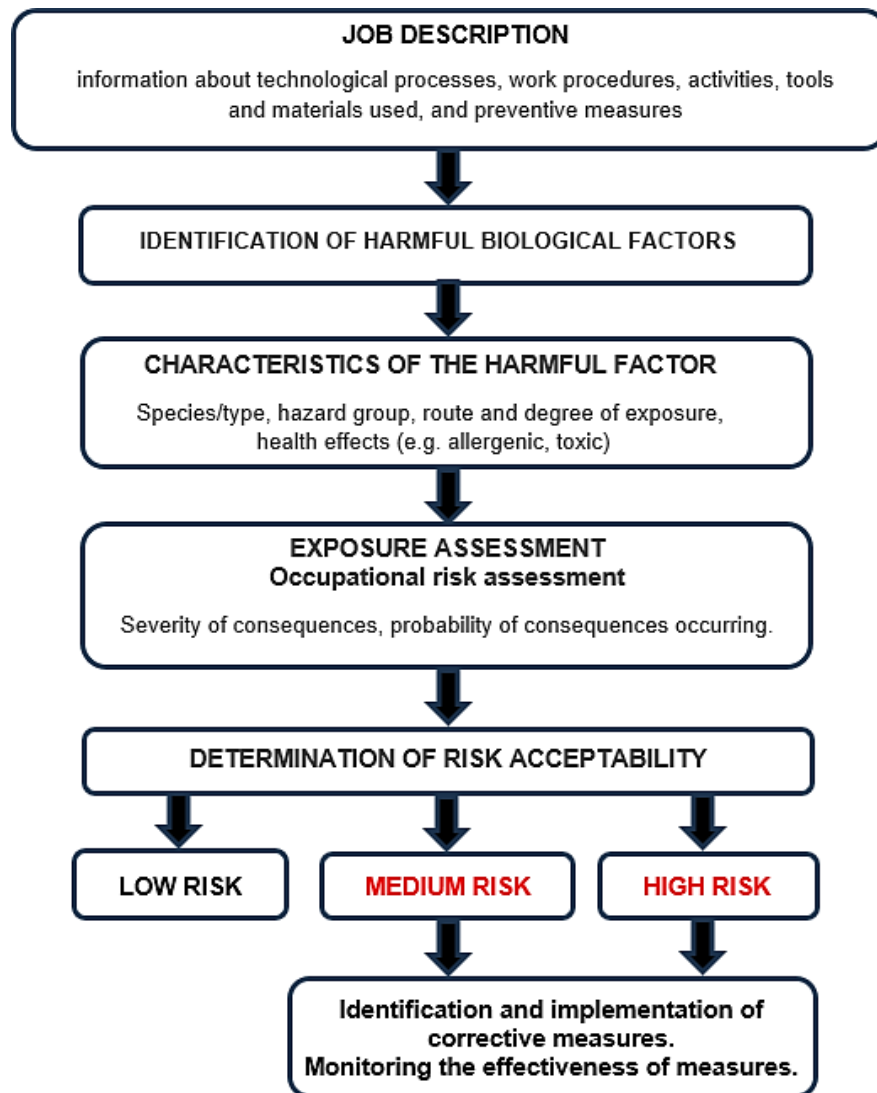


Figure 1. Stages of occupational risk assessment in exposure to harmful biological agents.

Source: own elaboration based on (CIOP, 2022).

Sources of biological agents ie:

- mine water: water samples were taken from various points, e.g. shafts, main drainage pumps, watercourses, pressure installation, fire pipelines);
- rock surface and structures: swab samples were taken, e.g., from the surface of the excavation and from the sides, pipes, conveyor belts, wooden elements of the casing, i.e., those places where fungi and bacteria can grow;
- air in the excavation: aerobiological measurements were taken using the impactor method to determine the concentration of bioaerosols (e.g., fungal spores);
- free-living rodents in mine workings: live traps designed to capture mice and rats were set in selected locations of underground mine workings for laboratory analysis to assess the health of rodents and the threat from them as reservoirs of pathogens. Animals were caught in accordance with the principles of humane treatment and biosecurity rigor;

- social and hygienic spaces of the mine, i.e.: baths, locker rooms and storage areas for work clothes. Particular attention was paid to damp and soiled clothes, and the floor of the bathhouse, areas that could be potential habitats for fungi, bacteria and biological allergens.

The information obtained allowed a thorough understanding of the research facility and the identification of potential sites of existing biohazard in both underground mine workings and employee welfare rooms located on the surface, which had to be subjected to detailed microbiological analysis and evaluation

3.2. Sampling and preparation for laboratory analysis

All activities related to the collection of samples for laboratory testing and the testing itself were performed by the staff of an accredited laboratory cooperating with the coal mine under study in accordance with the applicable standards (PKN 2002, 2005, 2007) and so:

1. Water sampling:
 - a) sterile bottles of volume usually 1 l, transport in a refrigerator (4 °C), delivery to the laboratory within 24 hours;
 - b) in the laboratory:
 - Culture on liquid and solid media (e.g., TSA agar for aerobic bacteria, Sabouraud agar for fungi).
 - Aerobic-anaerobic testing (incubation under anaerobic conditions for detection of absolutely anaerobic bacteria).
2. Collection of sediment and swab samples:
 - a) Sterile tubes, refrigerated transport.
 - b) Serial dilutions from 10^{-1} to 10^{-6} , culture on various media:
 - McCartney agar (for Gram-positive and Gram-negative bacteria).
 - Specialized media (e.g., medium for *Mycobacterium* sp. if tuberculous pathogens are suspected).
3. Air sampling:
 - a) Impactor (Andersen) with multi-hole discs, allows to classify the number of colonies according to particle size (e.g. 1-5 μm , >5 μm).
 - b) After collecting filter or plate with medium: incubation at 25-30°C (fungi) or 35-37°C (bacteria) for 3-7 days.
4. Analysis of captured rodents:
 - a) Live traps allowing live rodents to be transported to the laboratory within 24 hours.
 - b) In the laboratory:
 - Initial assessment of the physical condition of rodents, collection of biological samples (blood, oral and anal swabs, as well as internal organs after euthanasia under laboratory conditions).

- Bacteriological culture (including identification of *Leptospira*, *Salmonella*, *Yersinia*, *Escherichia coli*).
 - PCR methods (to detect genetic material of pathogens, including hantavirus and internal parasites).
 - Serological methods (determination of the presence of antibodies against specific zoonotic pathogens).
 - Parasitological analysis: stool and gastrointestinal tract sections were also tested for the presence of parasites (including nematodes, tapeworms, protozoa).
5. Social and hygienic spaces of the mine:
- a) Sterile tubes, refrigerated transport.
 - b) In the laboratory:
 - Microbiological testing of material samples taken from soiled and damp protective clothing, showing the presence of fecal bacteria, staphylococci and molds that can cause skin infections and allergic reactions in workers.
 - The cultures were performed on selective and differential media for Gram-positive and Gram-negative bacteria, as well as mold and yeast-like fungi.
 - The concentration of the total number of microorganisms was also determined, including the most common genera: *Aspergillus*, *Penicillium*, *Cladosporium*, *Candida*, *Staphylococcus*, *Bacillus*.

The described procedure made it possible to ensure the reliability and representativeness of the samples collected for laboratory analysis. Thanks to the use of standard procedures and the work of qualified personnel from an accredited laboratory, it was possible to maintain sterile conditions for the collection and transport of samples of water, sediment, air, rodents and materials from social and hygienic spaces. Appropriate culture and incubation techniques, as well as the use of PCR, serological and parasitological methods, made it possible to effectively identify potential microbiological and parasitological hazards in the mine's working environment.

3.3. Laboratory analysis and species identification

An analysis of the available literature on biological hazards (Dutkiewicz et al. 2007a, 2007b, EU-OSHA 2017) and the results of laboratory tests of collected samples were used to identify biological agents in the preparatory works department of the coal mine under study:

1. Colony morphology:
 - Color, shape, consistency, growth rate, characteristic features (e.g., green coloration of *Aspergillus* colonies).

2. Microscopy:
 - Gram staining (bacteria) and hyperpigmentation (fungi).
 - Evaluation of the shape of cells, spores, filaments - allows preliminary classification into genus.
3. Biochemical tests (bacteria):
 - Catalase, oxidase tests, API (Analytical Profile Index) or automated systems (e.g., VITEK).
4. Molecular methods (optional):
 - PCR using universal primers for 16S rRNA (bacteria) or ITS (fungi).

The described procedure allowed for the effective identification of biological agents present in the preparatory works department of the mine under study and the combination of literature analysis and laboratory results, which enabled an accurate assessment of microbiological risks. Meanwhile, the use of comprehensive identification methods, including evaluation of colony morphology, microscopy (including differential staining), biochemical tests or molecular techniques such as PCR. It enabled to precisely determine the type and species of microorganisms, which formed the basis for further biological risk assessment

4. Study results and discussion

The subject of research related to exposure to biological agents within the framework of the presented article was a coal mine located in Upper Silesia in southern Poland in the city of Ruda Śląska, in which the region of the coal gangway No. 4 in deck 504 drilled with the AM - 50 shearer towards the future longwall No. 8 by 68 employees of the preparatory works division GRP-1 was selected for detailed environmental studies (Figure 2). The subject of research related to exposure to biological agents within the framework of the presented article was the region of the coal gangway No. 4 in deck 504 drilled with the AM - 50 shearer towards the future longwall No. 8 by 68 employees of the preparatory works division GRP-1 of the X mine located in Ruda Śląska (Figure 2). The excavation with a cross-sectional area of 17.5 m² was ventilated by braze ventilation allowing about 850 m³ of airflow. Due to the difficult climatic conditions (air temperature exceeding 28.8°C and humidity oscillating around 93.0%), tunnelling was carried out in 4 shifts of 6 hours each.



Figure 2. The region of the excavated coal gallery No. 4 in the coal mine under study in seam 504.

Source: own study.

4.1. Stage I - Characteristics of workplaces in the area of the preparatory works division GRP-1 in the studied coal mine

In underground mine workings, exposure to biological agents is not a direct result of employment in a specific job position, but is closely related to the type of activities performed and the characteristics of the work environment. Activities exposing miners to harmful effects of biological agents in the area of the coal gangway No. 4 were, for example:

1. Mechanical mining of coal puddles.
2. The extraction of the bottom by hand mining of loose rock material.
3. Operation of electric, hydraulic and diesel mining machinery and equipment.
4. Manual transport of materials to the face.
5. Installation of elements of sidewalk lining ŁP-10.
6. Execution of the opinion of the roadway excavation or its regeneration.
7. Drainage of mine workings.
8. Installation and extension of brazing ventilation with the progress of the excavation.

In performing these tasks, miners employed at the GRP-1 division were exposed to a number of biological hazards, resulting from the presence of various microorganisms in the working environment. Among them were microorganisms that naturally existed in the ground and crushed rock material, as well as pathogens present in the underground water, such as *Legionella pneumophila* bacilli - responsible for legionellosis - and *Leptospira spp. spirochetes*, which cause leptospirosis. The miners were also threatened by mold fungi, including species of

the genera *Aspergillus*, *Penicillium* and *Cladosporium*, which, due to the humidity and high temperature in the pit, thrived intensively on moist surfaces and organic materials. The presence in the mine workings of wild rodents, mainly mice and rats, which may have been a reservoir and vector for many zoonotic diseases (zoonoses), including the aforementioned leptospirosis, as well as salmonellosis and hantaviruses, also appears to be of significance (Table 2).

4.2. Stage II - Identification of biohazards in the GRP -1 branch of the coal mine under study

Identification of biological hazards occurring in the area of hollow coal seam No. 4 of the coal mine under study was carried out in three steps:

- on the basis of an interview based on a created questionnaire - the so-called checklist (Table 3),
- a site visit combined with environmental and laboratory tests performed by an accredited laboratory cooperating with the coal mine under study,
- available literature (Dutkiewicz et al., 2007a, 2007b; EU-OSHA, 2017).

An interview conducted among the employees of the GRP-1 division excavating coal seam No. 4 showed that the miners are poorly aware of the biological factors present at their workplaces or accompanying technological processes. According to them, the employer has so far failed to inform them about this danger at safety training courses outside COVID-19. The miners themselves have become accustomed to hard work in underground conditions, ubiquitous dirt, moisture, dust, and the accompanying wild creatures (mice, rats) that often gorge on their food. Deprived of sanitary facilities in mine workings, they eat their meals on site often with unwashed hands.

On the other hand, they take care of their physiological needs in secluded places not too far from their workstations, dropping feces on coal spoil transported by conveyors. For the most part, miners are unable to break down biological agents, nor do they know what health effects they cause. For many years, the only ailments they were able to recognize in themselves were fungal infections of the feet and nails caused by biological agents, with which, despite the cleaning products and antifungal salves used, they persist. Some miners of the GRP-1 division also complain of skin lesions caused by having to work for several days in dirty clothes and not being able to change them daily.

There is a much greater awareness of biological hazards occurring at the mine, their possible sources and consequences among the employees of the occupational health and safety service, but, as they themselves admit, they did not pay more attention to them than required by the Labor Code and other legal regulations. This state of affairs changed after 2022 and the obligation imposed on the employer to assess risks in the case of biological hazards, so they carefully joined in the development of a procedure for their assessment.

Their joint efforts made it possible, based on laboratory tests and a literature review, to identify and classify biological hazards present at the coal mine under study (Table 4).

Table 2.

Stage I of the occupational risk assessment for harmful biological agents in the area of coal gangway No. 4 of the coal mine under study

OCCUPATIONAL RISK ASSESSMENT		
Basic information		
Workplace (name and address): Hard coal mine, Ruda Śląska, GRP-1 Division, Coal gangway No. 4 in deck 504		
Position/positions: Foreman, shearer miner, robber miner, conveyor operator, miner at manual handling, diesel train operator, mine carpenter.		
Number of persons covered by the risk assessment: 68 including juveniles: 0		
Employees covered by the risk assessment from groups particularly susceptible to harmful biological agents: <i>Enter an "x" next to the groups known to belong to at least one of the workers included in the list of persons covered by the occupational risk assessment.</i>	1. juveniles (persons between 15 and 18 years of age) - vocational and secondary school students	-
	2. pregnant or breastfeeding women	-
	3. persons aged 65+	-
	4. immunocompromised persons	X
	5. Employees with suspected occupational disease	-
Sources of harmful biological agents present in connection with the work process:		
1. Earth, soil fragmented rock mineral formed in the process of excavation of the rock mass containing micro and macroorganisms. 2. Wood, wooden stakes, lumber - used to protect the ceiling and chestnut free spaces, subject to the process of decay and decomposition. 3. Water of natural origin from the rock mass, watercourses and reservoirs containing microorganisms. 4. Process water used in the mining process, technological process, fire-fighting and dewatering installations. 5. Water-oil medium used to power hydraulic cylinders and installations, the side effect of which is oil mist. 6. Mine dust containing crushed particles of rock minerals and organic matter. 7. Humans-Continuous contact with several hundred co-workers who may be carriers of various viruses and bacteria. 8. Rodents: mice, rats living wild in mine workings that can be carriers of biological agents. 9. Human excrement and excreta associated with the lack of sanitary protection in mine workings. 10. Difficult microclimatic conditions conducive to the growth of fungi and bacteria. 11. Soaked work clothes conducive to the development of bacterial flora.		
List of activities performed that expose the worker to harmful biological agents:		
1. Mechanical mining of coal puddles. 2. Collection of the bottom, manual mining of loose rock material. 3. Operation of electric, hydraulic and diesel mining machinery and equipment. 4. Manual transport of materials to the face. 5. Installation of elements of sidewalk lining LP-10. 6. Execution of the opinion of the roadway excavation or its regeneration. 7. Drainage of mine workings. 8. Installation and extension of brazing ventilation with the progress of the excavation.		
Routes of exposure: <i>enter an "x" next to the probable routes of infection</i>	respiratory	X
	oral	X
	contact (skin, mucous membranes, eyes)	X
	blood-borne	X
Genetically modified microorganisms (GMMs)		YES
<i>(YES - present, NO - absent)</i>		NO
Other relevant information:	Unintentional exposures to biological agents in the work process	

Source: own compilation based on (Kozajda, Miśkiewicz, 2022).

Table 3.

Sample questions of the checklist conducted among the employees of the preparatory works division GRP 1 of the coal mine and health and safety services studied

Definition of work area			
Work area	Coal gangway No. 4 deck 504		
Number of employees	68		
Description of the performed activities	Tunnelling of the corridor excavation		
Exposure time	daily		
Information on harmful biological agents	Yes	No	Comments
Are there any factors from hazard group 2?	x		
Are there factors from hazard group 3 present?	x		
Are the factors present likely to enter the body by contact?	x		
Can the factors present penetrate the body through the oral route?	x		
Can the agents present penetrate the body by air?	x		
Do the biological agents present have an allergenic effect?	x		
Information about the course of work and professional activities performed			
What is the source of biological agents?			
- Is there contact with blood?		x	
- Is there contact with other organic material, human secretions?	x		
- Is there contact with diseased infected animals?	x		
Is the quantity (volume), concentration of the biological agent known?		x	
How often is the work performed in exposure to harmful biological agents?	x		268 days
How long can exposure to harmful biological agents last?	x		5 hrs.
Is there a possibility of injury?	x		
Have biological agents ever been measured?		x	
Have there been any illnesses among employees related to activities involving exposure to biological agents?	x		Mycoses cutaneous
Classification of activities			
Are intentional activities related to the use of SCBs being performed?		x	
Are only unintentional activities related to SCB performed?	x		
Protective measures used			
Are backfills with antifungal agents used prophylactically?	x		
Do employees have the ability to separate work clothes from civilian clothes?	x		
Does the employer provide regular cleaning and replacement of work clothes?	x		
Is there an opportunity to wash hands at the workplace?		x	
Technical measures			
Are mine workings mechanically ventilated?	x		
Are the mine workings air-conditioned?		x	
Is water quality controlled for biological hazards?		x	
Organizational measures			
Is there a procedure in case of injury or accident?	x		
Are immunizations administered at the facility?		x	
Is a procedure defined for disinfection of mine workings, work tools?		x	
Is there a ban on eating in the mine workings?		x	
Preventive measures			
Are clothing, gloves, work and protective footwear used?	x		
Is respiratory protection provided?	x		

Source: own compilation based on (CIOP, 2022).

4.3. Stage III - Estimation of biological risks in the preparatory works division

The estimation of occupational risks associated with exposure to biological agents in the miner's work environment involves a comprehensive assessment of the health risks that may arise from short-term or chronic contact with these agents. The purpose of this process is to determine the likelihood of health effects and their potential severity, in the context of protecting the lives and health of workers. The basis for this assessment was the biological hazards identified in Stage II in the preparatory works division GRP- 1 of the coal mine under study and the applicable classification of biological agents belonging to one of the four hazard groups (ISAP, 2020). The second extremely important aspect in the risk estimation process was to determine the duration and frequency of exposure. This allowed the estimation of exposure doses and thus the determination of the probability of health effects, which was particularly important for epidemiological investigations aimed at confirming a cause-and-effect relationship between exposure and the development of an occupational disease.

In practice, the occupational risk estimates carried out (Table 4) for workers employed in the area of coal seam No. 4, in deck 504 of the coal mine under study, indicate a significant biological risk. The greatest risks for miners of the GRP-1 Division are:

- melioidosis bacilli (*Burkholderia pseudomallei*) and *Rickettsia typhi*, which are spread by rats living in the workings;
- mycotoxins, produced by mold fungi that develop on wooden stamps, as well as on miners' dirty work clothes.

All of these agents belong to the third group of biological hazards, which means that even short-term exposure can lead to serious diseases, such as:

- melioidosis (purulent inflammation of internal organs and lymph nodes),
- endemic typhoid (rat fever),
- mycotoxicosis, involving damage to the liver, lungs or kidneys.

Miners working in the area are exposed to the above factors for up to 268 days a year, which significantly increases the likelihood of occupational diseases and requires the implementation of appropriate preventive measures and monitoring of workers' health.

Table 4.

Stage II and III of the occupational risk assessment for harmful biological factors identified in the area of coal gangway No. 4 of the coal mine under study

OCCUPATIONAL RISK ASSESSMENT											
Identification of harmful biological agents / Risk estimation											
	Risk group	Name of species/ genus.	Antibiotic resistance			Duration of exposure		Possible health effects			
			Yes	No	Highly likely	umber of days per month	Number of days per year	Allergic effects	Synthesis of sin x o t	Diseases or symptoms:	
Bacteria	Threat group 2	Clostridium perfringens		x		23	268		x	gas gangrene	
		Clostridium tetani			x	23	268		x	tetanus	
		Clostridium spp			x	23	268	x		Wound malignant edema, enteritis	
		Fluoribacter bozemanæ			x	23	268			pneumonia	
		Legionella pneumophila			x	23	268			legionellosis	
		Leptospira interrogans	x			23	268			leptospirosis, Weil's disease	
		Mycobacterium kansasii			x	23	268			pulmonary mycobacteriosis	
	3	Burkholderia pseudomallei	x			7	84			Melioidosis: acute lymphadenitis	
		Rickettsia typhi		x		7	84			endemic rat typhoid fever	
		3**	Mycobacterium tuberculosis			x	7	84			pulmonary tuberculosis
Viruses	Threat group	2	Hepatitis A virus, enterovirus type 72)		x		23	268			Hepatitis A, gastroenteritis
		3	Dobrava-Belgrade hantavirus			x	13	156			Hemorrhagic fever with renal syndrome (HFRS)
			Seoul hantavirus			x	13	156			Hemorrhagic fever with renal syndrome (HFRS)
		3**	Hepatitis B virus (HEPATITIS B, HBV)			x	23	268			Hepatitis B, a common form of chronic cirrhosis, liver cancer

Cont. table 4.

OCCUPATIONAL RISK ASSESSMENT											
Identification of harmful biological agents / Risk estimation											
	Group of hazard		Name of species/genus.	Antibiotic resistance			Duration of exposure		Possible health effects		
				Yes	No	Highly likely	Number of days per month	Number of days per year	Allergic effects	Synthesis of sin x o t	Diseases or symptoms:
Fungi	Threat group 2		Aspergillus flavus	x			23	268	x		Pulmonary mycosis; bronchial asthma carcinogenic effect.
			Candida albicans		x		23	268			Candidiasis of the skin, nails, oral cavity. AL. - endogenous allergic reactions.
			Candida tropicalis			x	23	268			Candidiasis of skin, nails, urinary tract infection.
			Epidermophyton floccosum			x	23	268	x		Dermatophytosis (dermatophytosis), allergies.
			Trichophyton rubrum			x	23	268			Dermatophytosis (dermatophytosis), allergies.
	3	Mycotoxins produced by many mold fungi			x	23			x		Mycotoxicosis poisoning of internal organs mainly liver, lungs, kidneys), carcinogenic effect.
Parasites	Threat group 3	2	Ancylostoma duodenale		x		13	156			Ankylostomatosis, diarrhea, larvae-induced pneumonia.
			Balamuthia mandrillaris		x		13	156			Pneumonia, encephalitis, dermatitis, keratitis.
			Necator americanus		x		13	156			Antilostomosis (tunnel disease), diarrhea pneumonia caused by larvae.
	3**	Strongyloides stercoralis		x		7	120				Echinococcus, for diarrhea pneumonia, and, less frequently, meningitis.

Source: own compilation based on (Kozajda, Miśkiewicz, 2022).

4.4. Stage IV - Corrective and preventive actions

The result of carrying out an occupational risk assessment of exposure to biological agents in the work environment should be the prioritization of actions aimed at reducing the risk, especially in positions where its level has been assessed as high or very high. The key here is to determine both the type of biological agent and the time, frequency and intensity of exposure.

In cases where exposure to biological agents is the result of their intended use (e.g., in laboratories or biotechnology production), the optimal solution is to replace the hazardous biological agent with a safer counterpart. However, in a working environment such as underground mining, where exposure is unintentional, resulting from the presence of, for example, microorganisms, rats, animal excrement or mold, the use of this method is impossible in practice. In this situation, according to the current regulations contained in the Ordinance of the Minister of Health of March 11, 2024 on harmful biological agents in the work

environment and the protection of the health of workers occupationally exposed to these agents (ISAP 2020), the employer is obliged to take all possible measures to eliminate or reduce the exposure of workers to biological hazards. This includes:

- eliminating biological agents from the work environment, if possible,
- controlling technological processes and work organization to reduce contact with harmful agents,
- informing and training employees about biological hazards and proper conduct,
- conducting medical surveillance, especially in cases of infectious diseases or suspected occupational disease.

The biological risk assessment carried out for employees of the GRP-1 Branch working on the excavation of coal seam No. 4 in deck 504 revealed significant biological risks that had not previously been prioritized by the occupational health and safety services. Among the identified factors were:

- mold fungi (mainly *Aspergillus* and *Penicillium*),
- *Burkholderia pseudomallei* bacilli - the etiological agent of melioidosis,
- *Rickettsia typhi* - transmitted by rats, causing endemic typhoid fever.

Sources of these hazards include decaying organic materials (wood, garbage), moisture and high temperatures in pits, improper storage of work clothes and the presence of free-living rodents.

The assessment showed that:

- most workers had no knowledge of biological hazards or protective measures,
- there was no previous prophylaxis targeting biological agents,
- activities were limited to: provision of work clothes, basic personal hygiene, availability of antifungal soaps and drippings, and general deratization.

The analysis of occupational risk for biological hazards in the area of coal heading No. 4 (seam 504) showed that the existing activities of the occupational health and safety services-according to the guidelines of the Institute of Occupational Medicine in Łódź (Kozajda, Miśkiewicz, 2022) and the Central Institute for Labor Protection in Warsaw (CIOP 2022)-have proved insufficient both in the underground workings and in the surface facilities (baths, changing rooms). Not only were group 2 and 3 pathogens (bacteria, viruses, parasites, fungi) found there, but also cases of diseases such as skin mycosis, nail candidiasis and food poisoning.

Table 5.

Stage IV of the occupational risk assessment for harmful biological agents identified in the area of coal walkway No. 4 of the coal mine under study

OCCUPATIONAL RISK ASSESSMENT					
PREVENTIVE MEASURES					
Substitution of harmful biological agents				Collective protection measures / Procedures	
				Technical measures used:	Procedures used:
impossible	x			Portable sanitary cabins and toilets	Initial and periodic health and safety training
possible				Mechanical dust collectors	Washing and disinfection of work clothes
If possible, whether it has been done:				Local water sprinklers to reduce dust	Periodic preventive examinations of employees
NO		YES			
if substitution has been made, enter factors before and after substitution:				Proposal for additional technical measures.	Proposal to implement additional procedures
1.				Ozonators for sanitary rooms	Deratization of mine workings
Replaced:				Bactericidal UV lamps	Health education
2.				Biofilters and biological reactors in water systems	Application of biocides in water systems
Replaced:					Impregnation of wood, stamp lumber
Proposal for protective vaccination				Personal protective measures:	
Vaccination against hepatitis B.				Respiratory protection	x Filter masks of FFP2, FFP3 class.
Vaccination against tetanus bacillus.				Skin protection	x Cotton work clothes
Vaccination against leptospirosis.				Face and eye protection	x Safety glasses and goggles
				Leg protection	x Rubber footwear
				Hand protection	x Leather gloves
				Cleaning products	x Soaps, antifungal salves

Source: own compilation based on (Kozajda, Miśkiewicz, 2022).

To significantly reduce workers' exposure to biological agents, it is recommended that the existing package of protective measures (clothing, masks, basic disinfection) be supplemented with the following coordinated preventive measures (Table 5):

- Permanent deratization of mine workings and surface facilities, especially near social areas.
- Use of biocides in water systems and drainage systems - both underground and surface.
- Impregnation of wood used in mine workings (stamps, temporary casings, helmets) with anti-fungal and anti-bacterial preparations.
- Introducing disinfection of social rooms, using ozone or UV-C radiation, scheduled at least once a week.
- More frequent laundering and disinfection of work clothes - daily if possible, or after each shift, with agents to combat spores and mycotoxins.
- Introducing biological decomposition activators for organic waste, including fecal matter and sewage sludge in social facilities and underground water drainage systems.

In addition, due to the unintentional but persistent exposure of miners to group 2 and 3 biological agents, it is necessary to expand preventive medical care:

- inclusion of periodic examinations aimed at early detection of bacterial, viral and fungal infections,
- consideration of immunizations (e.g., hepatitis B, leptospirosis, rabies) based on local epidemiological risks,
- implementation of post-exposure prophylaxis, i.e. procedures for rapid access to medical care, including specialist consultations and implementation of antibiotic prophylaxis or antiviral/fungal treatment in accordance with current guidelines.

Such a coordinated program of measures - combining technical, organizational and medical countermeasures - will make it possible to realistically reduce the risk of infections and occupational diseases among miners working in harsh mine conditions.

4.5. Stage V - Informing employees about occupational risks, reviewing and updating the risk assessment

The obligation imposed on the employer to inform employees about biological risks in the workplace is not only a legal requirement, but above all a necessity to protect the health of employees. In light of the Decree of the Minister of Health of December 11, 2020 and EU Directives: 2019/1833 and 2020/739, employers must systematically update the assessment of health risks associated with exposure to biological agents and take preventive measures to reduce existing risks. Such practice contributes to reducing occupational illnesses and building a proactive safety culture in the workplace.

As illustration of the practical implementation of the above requirements, reference can be made to the charter of stage V of the risk assessment for employees of the preparatory works division GRP-1 of the coal mine under study (Table 6), which includes:

- a list of persons familiarized with the results of the occupational risk assessment,
- registered cases of health problems among miners caused by biological factors.
- information on preventive measures taken to reduce the number of illnesses and ailments among the mining crew,
- information on the need to conduct an additional risk assessment, including after disinfecting the wooden casings and wooden lining of coal walkway No. 4.

Thanks to this, both the employer, occupational health and safety services and the employees themselves have the opportunity to control the effects of measures taken to reduce biological risks at workplaces.

Table 6.

Stage V of the occupational risk assessment for harmful biological factors identified in the area of coal gallery No. 4 of the studied coal mine

OCCUPATIONAL RISK ASSESSMENT						
Informing exposed workers about the result of the occupational risk assessment: <i>List with signatures of persons informed of the result of the occupational risk assessment</i>						
Date	Name of the person responsible for informing workers		Workers informed about the result of occupational risk assessment			
yyyy-mm-dd	Name		Name	Handwritten signature		
2024.01.02	Branch manager Piotr Muś		Jan Kowalski	Kowalski		
2024.01.02.	Branch manager Piotr Muś		Adam Nowak	Nowak		
2023.01.02.	Branch manager Piotr Muś		Karol Wisniewski	Wisniewski		
Monitoring the effectiveness of preventive measures						
Date yyyy-mm-dd	Description of health problems reported by employees caused by biological agents		Number of reports	Corrective actions taken		
2024.02.20	Dermatophytosis		7	Disinfection of employee baths, increase frequency of washing work clothes		
2024.03.08	Candidiasis of fingernails and foot skin		10	Referred for medical consultation		
Accidents and other incidents/incidents involving biological agents						
Date of event yyyy-mm-dd	Description of the incident involving a biological agent	Number of injured persons:	Was post-exposure treatment implemented?			
		total	YES	If YES what kind?)		NO
2024.04.10	Cut wound of the foot/ Clostridium tetanii	1	x	Wound disinfection, vaccination Against tetanus bacillus		
Verification of risk assessment						
Date dd-mm-yyyy	Name of person responsible for verification	Is there a need to make changes to the risk assessment?		If YES, what changes should be made? As of when they will be implemented (enter date dd-mm-yyyy)		
		NO	YES			
2024.03.20	Jan Lis - health and safety inspector	x		Carry out deratization of the pit. Until 20.04.2024.		
2024.08.11	Jan Lis - health and safety inspector		Yes	Carry out disinfection of the chestnut and wooden opinion in the coal walkway No. 4 by 10.09.2024		

Source: own compilation based on (Kozajda, Miśkiewicz, 2022).

5. Conclusions

As shown in the study (stages I to V), the environment of coal mines, characterized by high humidity, elevated temperatures, the presence of organic substances and limited ventilation which creates favorable conditions for the development of microorganisms - bacteria, fungi, viruses and their metabolites (Table 4). As a result, mining workers are exposed not only to physical and chemical hazards, but also to serious biological hazards that can lead to the development of occupational diseases, primarily from the respiratory system and skin

(Cheluszka et al., 2023; Rdzanek et al., 2015), so measures should be taken immediately in mines, not only coal mines, to identify, assess and reduce biological risks.

Unfortunately, despite the growing interest in this problem in research conducted around the world, identification of biological risk factors in mines and accurate assessment of occupational exposure remains a challenge due to the complexity of exposures, lack of legal standards and limited availability of modern detection methods.

The main problem in identifying biological risks in the mine environment is the multicomponent nature of bioaerosols. Thousands of different microorganisms are detected in mine air: saprophytic and pathogenic bacteria, microscopic fungi (mold and yeast-like), actinomycetes, and sometimes viruses and mycotoxins (Wei et al., 2015; Xue et al., 2022). Due to the limitations of classical microbiological methods (culture on agar), a significant proportion of these organisms remain undetectable, leading to underestimation of risk (Montano, 2014).

Studies using molecular methods (PCR, 16S/18S rRNA sequencing, metagenomics) have shown that classical culture tests reveal only a fraction of the microbiome present in dust and mine aerosols (Wei et al., 2015; Cheluszka et al., 2023). High-throughput sequencing can detect potential opportunistic pathogens, such as *Klebsiella pneumoniae*, *Burkholderia cenocepacia*, *Acinetobacter spp.*, *Aspergillus flavus* and *Stachybotrys chartarum*, which can cause infections in immunocompromised individuals (Xue et al., 2022; Sharma, Sumbali, 2019). However, even these advanced methods do not provide a complete picture of exposure - they do not report on the viability of the organisms, infectious doses or toxicity of metabolites.

Another barrier to effective identification and management of biological risks in mines is the lack of uniform international standards for acceptable concentrations of bioaerosols and their components (NIOSH, 2017). In most countries, including Poland and China - where the most research has been conducted - there are no legally binding limits for the number of microbial cells per cubic meter of air in underground working environments (Cheluszka et al., 2023; Wei et al., 2015). Instead, general guidelines for confined environments or interpretation based on literature "warning values" are used.

The complexity of biological risk also stems from the difficulty of establishing a dose-response relationship. There are no precise data on what concentrations of *Aspergillus fumigatus* spores or lipopolysaccharide endotoxins will cause allergy, pneumonia or infection in the average miner (Montano, 2014; Rdzanek et al., 2015). As a result, researchers use the concept of "unit concentration", analyzing the composition of bioaerosol qualitatively and comparatively, without being able to fully assess the quantitative risk (Cheluszka et al., 2023).

Occupational risk assessment of exposure to biological agents in mines is most often based on a combination of qualitative and quantitative methods. Cultures of microorganisms from air and surface samples, identification of organisms by molecular methods, measurement of concentrations of endotoxins, β -glucans or mycotoxins, and environmental assessments

(humidity, temperature, presence of organic materials) are used (Wei et al., 2015; Cheluszka et al., 2023).

Metagenomic approaches and QMRA (*Quantitative Microbial Risk Assessment*) models, which attempt to estimate health risks based on exposure data, pathogen characteristics and population susceptibility, are also increasingly being used (Sharma, Sumbali, 2019). However, the availability of such analyses is limited to countries with adequate laboratory and financial facilities.

On a practical level, occupational risk assessment faces numerous difficulties: lack of systematic microbiological monitoring, low awareness of biological risks among employers, health and safety services and workers, and insufficient personal protective equipment (e.g., ineffective dust masks, dust gloves) (Cheluszka et al., 2023). In many cases, there is also a lack of correlation between the microorganisms found and clinical symptoms in workers - epidemiological data are fragmented, and cases of infection are often not reported as occupational (Rdzanek et al., 2015). This state of affairs causes employers and occupational health and safety services to be reluctant to deal with biological hazards, which are a side element of the mainstream production of a mining plant or mine, despite changes in EU and national law.

The descriptive method of biological risk assessment presented in the article, the methodology for conducting the identification of biological hazards presented and implemented on a specific example - the preparatory works department of a coal mine, showed that the process of analyzing and estimating the health effects of exposure to biological agents does not have to be complicated. Having the right pattern of conduct based on empirical and literature data, the services of any workplace where biological hazards occur as a side element of the main manufacturing process should cope with the assessment of biological risks. In addition, the biological risk data collected in this way can be used for further scientific research and practical solutions aimed at:

1. Standardize methods for measuring bioaerosols by introducing global protocols for sampling and microbiological analysis to enable data comparisons between countries and mines.
2. Develop occupational exposure standards and establish permissible levels of exposure to the most common microorganisms and metabolites in mine conditions.
3. Expanding the use of molecular and metagenomic methods to detect a wider spectrum of microorganisms and better identify opportunistic pathogens.
4. Conducting detailed epidemiological studies that include combining microbiological data with worker health information (e.g., spirometry results, allergic symptoms) to identify causal relationships.
5. Implementing more effective prevention based on solutions: technical (specialized air filtration systems, drying of clothes, monitoring of microclimatic conditions); organizational (integrated schedule of deratization and disinfection); individual

(ffp3 masks, antibacterial clothing and waterproof gloves) to educational (OSH training and employee education), which should significantly reduce biological risks in the work environment.

6. Protecting the health of workers by using biological risk assessment methods to ensure that working conditions comply with international standards and national regulations.

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IMPLEMENTING IBP/S&OP PROCESSES – THE MAIN MISTAKES USING THE EXAMPLE OF A GLOBAL COMPANY

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Purpose: For big companies the S&OP Process previously “just” the tool to prepare supply chain for expected volumes is now becoming the tool to deploy strategy. And as such, it is and should not be any longer considered as a “supply chain thing”, the process is becoming a core process of the organization. Especially in complex organizations the transparency is very often limited and different parts of the organizations loose connection due to multi-level data aggregation delay in information transmission. The implementation of the S&OP process is yet not easy. The case study described in this paper shows some of the mistakes the companies make on the journey towards the IPB process.

Design/methodology/approach: The paper is a case study of an industrial company. The baseline for the paper was documentation of a implementation project done in a global company. Additionally wide literature study on the topic has been conducted.

Findings: The conclusions of the case study are in line with the findings presented in the literature. One of main factors leading to not effective S&OP process is lack of high management support and engagement.

Research limitations/implications: The case study was based on a global company so the conclusions cannot be applied to other companies. The study uses data from 2021-2023 because the effect of implementation is only visible after 1-3 years on average.

Practical implications: The paper can be an inspiration for the people implementing IBP process in a global company.

Originality/value: The authors presented in the paper an original handy method to measure the development in the process in the company and draw conclusions on focus areas for the development of the process. Also the methodology of the process implementation is presented with guidelines based on lessons learned from the project.

Keywords: IBP, Integrated Business Planning, SAP IBP.

Category of the paper: case study.

1. IBP/S&OP processes – state of the art

Integrated Business Planning (IBP) stands for integrated business planning process which is the successor of the sales and operations planning (S&OP) process known from the 80's last century. The process has developed throughout the years yet still the key is about balancing demand and supply. These days IBP is a comprehensive approach that aligns strategic, tactical, and operational planning across an organization to enhance decision-making and performance. The key components of an IBP process usually include:

- strategic planning - among others: a) long-term goals - establishing the long-term objectives and direction of the organization (Kepczynski et al., 2018a; Mc Loughlin, 2023), b) alignment with business priorities - ensuring that strategic plans are linked to business priorities and other initiatives (Kepczynski et al., 2018b),
- tactical sales and operations planning (S&OP) – among others: a) demand and supply review - regularly reviewing product demand and supply to ensure balance and alignment, b) integrated reconciliation i combining inputs from various functions to create a unified plan, c) management business review - periodic reviews by senior management to ensure alignment with strategic goals (Kepczynski et al., 2018a, 2018b),
- operational planning – among others: a) execution of plans - implementing detailed plans to ensure reliable and effective execution in the manufacturing environment and market, b) dynamic adaptation - adapting plans based on real-time information from the plant and supply chain (Smith, 2004),
- integration of business processes – among others: a) cross-functional collaboration - promoting collaboration across different functions and departments to achieve synergy (Ivanisevic et al., 2020; Ni, 2006) b) information sharing - ensuring seamless information flow between different systems and stakeholders (Chen, 2007),
- technology and systems integration – among others: a) enterprise resource planning (ERP) and business process management systems (BPMS) - integrating ERP with BPMS to enhance performance and flexibility (Aguirre-Mayorga, 2012), b) standardized integration architecture - using a standardized architecture to integrate various software applications and legacy systems (Puschmann, 2004),
- performance monitoring and evaluation - among others: a) continuous improvement - regularly monitoring and evaluating performance to identify areas for improvement (Mc Loughlin, 2023), b) feedback loops - implementing feedback mechanisms to refine and adjust plans based on performance data (Basavaraju, Fatahi Valilai, 2025),

- sustainability and governance – among others: a) sustainable supply chain management (SSCM) - integrating social, environmental, and economic goals into the planning process (Gracia, Quezada, 2016), b) governance structures - establishing governance frameworks to oversee the integration and execution of plans (Mc Loughlin, 2023),
- organizational structure and competencies – among others: key roles and functions - defining roles and functions that facilitate integration and collaboration across the organization, b) capability overlap - ensuring that key functions have overlapping capabilities to enable seamless integration (Kepczynski et al., 2018b).

The Sales and Operations Planning (S&OP) plays a crucial role in the Integrated Business Planning (IBP) process by ensuring alignment between various business functions and the overall strategic goals of the organization. Here are the key roles and contributions of S&OP in IBP:

- alignment of strategic and operational plans - S&OP bridges the gap between the strategic plan and daily operational plans, facilitating the alignment of demand and supply for products. This ensures that the company's long-term strategy is consistently reflected in its day-to-day operations (Fakhry et al., 2024; Tuomikangas, Kaipia, 2014),
- cross-functional integration - it improves integration and communication between different business functions such as sales, marketing, finance, and operations, aligning them into one cohesive set of plans. This cross-functional collaboration is essential for achieving corporate performance targets (Danese et al., 2018; Ohlson et al., 2022),
- visibility and accountability - S&OP provides visibility into the business, helping stakeholders understand the balance between supply and demand. It also establishes greater accountability by holding the operational team to a common set of objectives (Affonso, 2008),
- decision-making and resource allocation - the process enables decision-makers to reach consensus on a single operating plan that allocates critical resources effectively. This consensus-driven approach ensures that all departments are working towards the same goals (Chiappinelli, 2008),
- risk management - in dynamic and volatile business environments S&OP incorporates uncertainty management strategies to address unpredictable factors like demand fluctuations and supply disruptions. This risk-focused approach helps organizations navigate complexities and maintain competitiveness (Fakhry et al., 2024).

IBP process is yet something more than just S&OP process; it includes inventory optimization and more over assumes integration with Finance and other functions like Product and Portfolio management, Marketing and Procurement. As such, Olivier Wight sees the IBP process as key process connecting operations to strategy of the organization (Palmatier, Crum, 2013) (Figure 1).



Figure 1. Olivier White's Integrated Business Planning process.

Source: Palmatier, Crum, 2013.

Implementing IBP can be fraught with challenges and mistakes. Based on the literature review, several common pitfalls can be identified: misalignment with organizational structure and culture (Morton, Hu, 2008; Ravasan et al., 2015), inadequate strategic planning (Gulledge et al., 2005), poor planning and execution (Peci, Vazan, 2014), failure to address misalignments (Wei et al., 2005), lack of management education and support (Cunningham, 2004), ignoring post-implementation issues. Critical success factors for IBP implementation encompass top management involvement, vendor support, and the presence of a champion, among others (Ramayah et al., 2007; Bradley, 2008).

2. The IBP frame work

Independently how IBP is called in different organizations, it normally consists of the below steps:

- product management review,
- demand planning,
- inventory planning,
- supply planning,
- reconciliation review,
- pre- S&OP meeting,
- management business review.

First step of IBP process should be Product management review. In this step all the assumptions for future demand are gathered and documented; the assumptions are mainly related to strategical inputs from the market and product life cycle management. This step is often mentioned as the step differentiating S&OP process from IBP process.

The next step is demand planning, where the actual forecasting happens. Forecasted volumes are then reviewed and verified with each market finally should be acknowledged with head of sales. Once the forecasted volumes are agreed and signed-off by the sales, they are the input to the next steps of the process. Next step of the process is Supply Planning including inventory planning. In the inventory planning the main goal is to set up needed inventory levels to secure the expected demand with requested service level. In this step plan for every part is decided resulting in materials management strategy. Once this is done the supply planning step is starting, the demand is distributed throughout the supply chain resulting in supply plan for every step of the supply chain. Main goal here is to secure that supply is able to secure needed demand. That is why rough cut capacity planning is done. At this step potentially the demand is constrained by e.g. capacity limitations or supply limitations. All the issues identified in supply planning step should be gathered, prioritized and solved or raised during the management review step.

After supply planning phase integrated reconciliation step is performed. This step is needed to align potentially three different plans: demand plan, constrained demand plan with financial plans. All gaps should be understood and documented.

The process is regular monthly and always should include all the steps. It results with one set of the data aligned with all the functions – it should be one single source of the truth.

There are various benefits of having IBP process in place. First and most important to be proactively prepared for evolving customer needs. The companies want to foresee what the customers will buy and prepare whole supply chain for this volumes. In order this happens it must be ensured that the plan is realistic. This is why the unconstrained demand plan gets often constrained and feedback is given to the sales that some of potential sales cannot be fulfilled, what protects the customers from delays. IBP process is also helping to efficiently manage change: different scenarios are analyzed beforehand so that the supply chain is prepared to catch opportunities and minimize negative impact in case of any negative changes. Maybe the most important benefit of having the IPB process in place it supports and measures business plan i.e. it is a tool to deploy the strategy. And last but not least benefit of IBP: it helps to build the team work, by removing the silos and helping to take global decision towards the same goal.

As all the processes, also IPB process 3 pillars: people, process, technology.

3. Case study

3.1. Before implementation

The company described in the paper is an international global company operating in the HVAC business. The scope of the implementation was one of the 5 sectors. This sector accounts for about 20% of the overall company's revenue and has strategic target of organic growth of 5% yearly mainly on the project driven products. This ambitious target created need of improved dialogue between operations and sales to identify and catch all growing opportunities.

The supply chain of this sector is presented on figure **Błąd! Nie można odnaleźć źródła odwołania.** and consists of 2 central hubs in 2 European countries and 3 supporting warehouses in 3 non-EU countries delivering the goods to 30 sales offices covering above 50 countries. The goods are produced by 4 factories located in 4 EU countries.

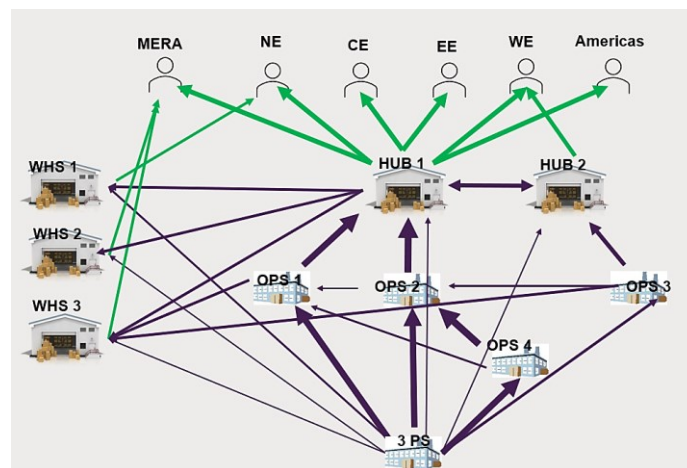


Figure 2. Supply Chain of the Sector covered by implementation.

Source: own research.

Before start of the project described in this paper the company had problems with meeting the budgeted revenue, additionally there were problems with transparency and difficulties with connecting sales figures to the factory plans. As source of the problems the management indicated poor S&OP process. There was already a S&OP process lead by Supply Chain with demand planning team yet monthly meetings were not held and there was no connection to financial forecasting process. As the root cause of such situation many stakeholders indicated the lack of IT tool. In such complex organization, multiple excel spreadsheets were not connected and as a consequence the process could not be properly executed. At that point of time the decision was taken to implement the IT tool to support the process.

Before doing that, the company has performed a survey to judge the company's process maturity, this survey showed that we are on the basic or survival mode in the IBP process. The company's management had the ambition to be on the advanced or best in class level.

The results of this survey and the goal the company has set before the implementation are shown on 3. Bottom line is the maturity level at the Company in 2021, before the implementation the top line is the expected state after the implementation.

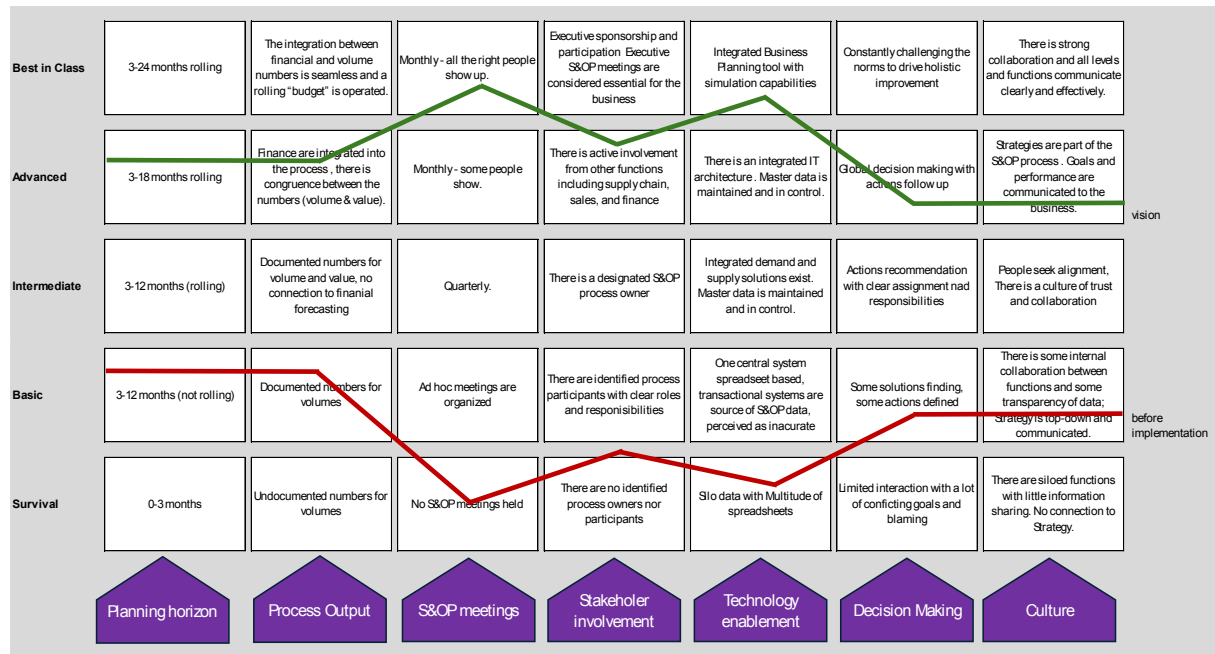


Figure 3. IBP process maturity level Survey.

Source: own elaboration.

3.2. Scope of the implementation

As described before, the scope of the project did cover one sector of the Company with quite complicated supply chain visualized on figure 2. This part of the company delivers about ~15000 SKU's of Finished goods divided into 3 product groups, 110 subgroups; in active bom's there are ~30 000 Components, semi-finished goods and raw materials delivered by ~450 Suppliers; in the 3 factories there are ~700 Workcenters located in 40 production cells.

As the technology enablement was identified as the area being the root cause of the poor IBP/S&OP process, the Company decided to run one project dedicated both to:

- implement IT tool to support the process,
- develop existing S&OP process and transform it to IBP process.

The IT tool was selected before starting the project. It was dedicated tool from one of the leading providers: SAP IBP. The expectations were that this choice should help to improve the process as implementation partner should have some benchmarks and standard solutions.

On Table 1 initial project plan is shown. The expected project duration was 1 year, this included both: IT tool implementation and S&OP process improvement and transformation into IBP Process. The project plan (shown on Table 1) was split into phases (sprints) following steps of the S&OP process.

Table 1.
Initial project plan with deliverables

Timeline	Project phase	Deliverables
2022 January	Kick-off	High level requirements Project team
2022 March	Preparation	To-be process map Mock up's
2022 June	Demand planning	Capture forecast from customers Forecast review with countries Final demand plan signed off by head of sales
2022 July	Inventory optimization	Plan for every part Safety stock levels
2022 September	Supply planning	Finished goods supply plan Rough cut capacity planning Inventory level projection
2022 December	S&OP fine tuning and transformation to IBP	Executive meetings

Source: own elaboration.

Each sprint was split into the following parts:

- to be detailed process design: this phase included detailed user stories build that were later used for testing,
- build phase- phase where IT system was adopted to the requirements stated in previous step,
- play back- step where the solution was presented by the implementation company in the testing environment,
- user acceptance testing – step where the key users tested the system and approved or rejected the solution,
- cut over – step where the tested solution was promoted to life environment,
- go live & hypercare - start of the life environment.

3.3. Project implementation

The project did kick-off as planned, the aim of first phase was to be ready with demand planning process using the tool within 6 months. As mentioned before, the company had before the project start team responsible for S&OP process, so naturally all of team members were chosen as key users for the project. On top of it steering committee was organized. The steering committee consisted of: Supply Chain manager, Head of Sales, Head of Procurement and Financial controller. The project managers were appointed both: on implementation company side and business side. The project meetings were held weekly for team members, monthly with steering committee.

Preparation phase was finalized with some delay. Main challenge noticed here were lack of interest of steering committee. Still the main focus was kept on the IT tool, not the process, so the lack of engagement of other than supply chain functions was not considered as a show stopper at this moment. The project was continued.

Next Sprint was dedicated to demand planning phase. The expected deliverable of this step was the demand plan for all the countries signed off by Head of sales. SAP IBP tool was great support in this phase as its advanced statistical tools give possibility of using historical data. This was not yet fully utilized as many of the users were attached to previous process, where a lot of manual interventions happened. The requirements from the core team were to have a process very similar to the one that was already existing. This caused many customizations leading to much more efforts on IT side and too little focus on process part including engagement of the sales team that was to be end users of the process. The result of many customizations of the SAP IBP tool lead to very complex process, not easy to understand by the stakeholders. On top of this many problems with integration of the SAP IBP with existing other IT systems in the company were noticed (figure 4).

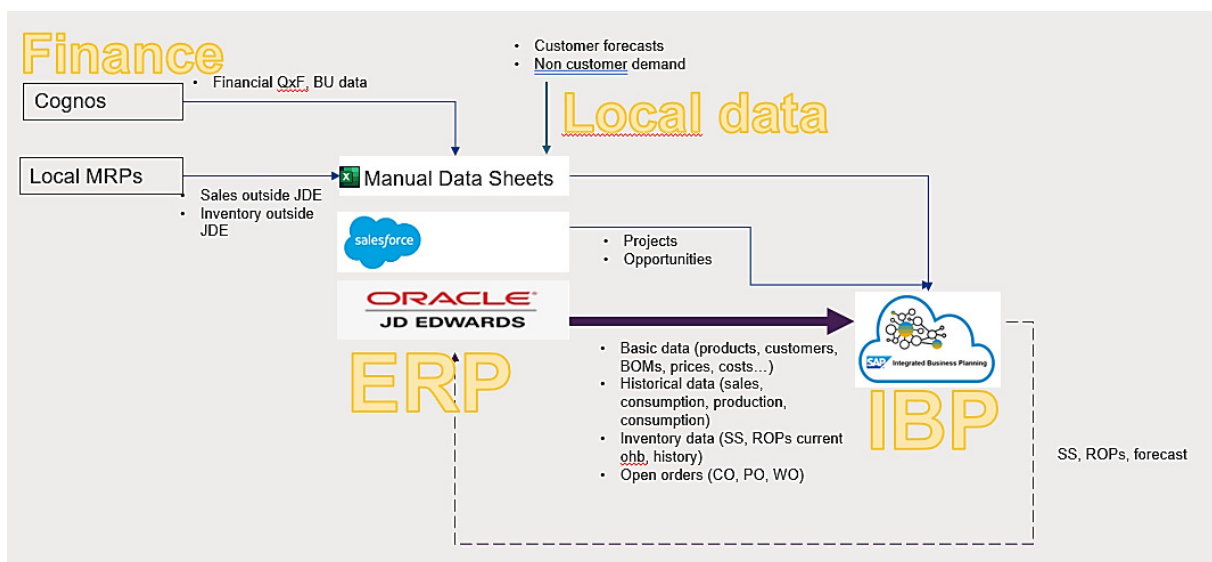


Figure 4. Connection between IT systems.

Source: own elaboration

As shown on Figure 4, main source of master and transactional data was Company's ERP system. The data flows were designed to be automatic with weekly or monthly frequency. This taking into consideration the nature of the S&OP process is satisfactory frequency. Mapping of the master data used in first sprint (products, customers, prices) was not as easy as initially forecasted. This was caused mainly by complexity of the supply chain and mistakes or missing data in source system. Transactional data mapping was also difficult due to the fact that some flows were covered outside main ERP system, what created the need of many workarounds. As the result of the above the project in this step was seriously delayed. The tests done by key users with not complete data were not fully reliable and next few months were

spent on gap closures until the demand planning phase could be fully closed. As a lesson learned from this step the team managers decided to appoint one key user to be responsible for data integration.

The next step, Inventory planning phase, was considered before the implementation as an easy one. The project had dedicated and educated key users and the functionality of safety stock calculations was well understood. Yet main challenge encountered on this step was bad forecast accuracy in first months of the demand planning implementation. This was resulting in too high safety stock calculations not possible to execute in real life. It resulted in the situation, where the process was executed by the users yet did not lead to business decision, creating confusion on all levels.

When starting Supply planning phase, the Company decided to use more agile approach resulting in 2 steps:

- implementation of standard functionality of IT system,
- adding necessary customization.

This approach led to limited number of customizations and much smoother testing phase. Also the understanding of the process by key users and end users was on satisfactory level. This was considered as a success. The main challenge identified in this step was too low engagement of executives. This problem, although visible from the beginning of the project, at this stage was a showstopper. Due to lack of support of the management, the execution of the supply plan was not sufficient resulting with big deviations between plan and actuals. The supply plan created in the process was not written back to the company's ERP system. This situation resulted in low engagement of the team members and difficulties to understand the capacity issues occurring, yet not visible beforehand, what is one of the biggest benefits to have S&OP planning. On top of this, the not satisfactory level of master data noticed already in demand planning phase, at this stage of the project, created many problems and led to need of master data cleaning activities. This was time consuming and not planned.

It was after finishing supply phase, when the Company started the S&OP meetings. When having the financial representative on board, another requirements to the process were stated. The connection to financial planning was next challenge, not being clear when starting the process. This is why the project was expanded to cover also this requirement. Fortunately this was a breaking point in the project. Finally the executive team started to gain interest some in the process and even though it required more work on IT side, the benefits of the process were started to be acknowledged.

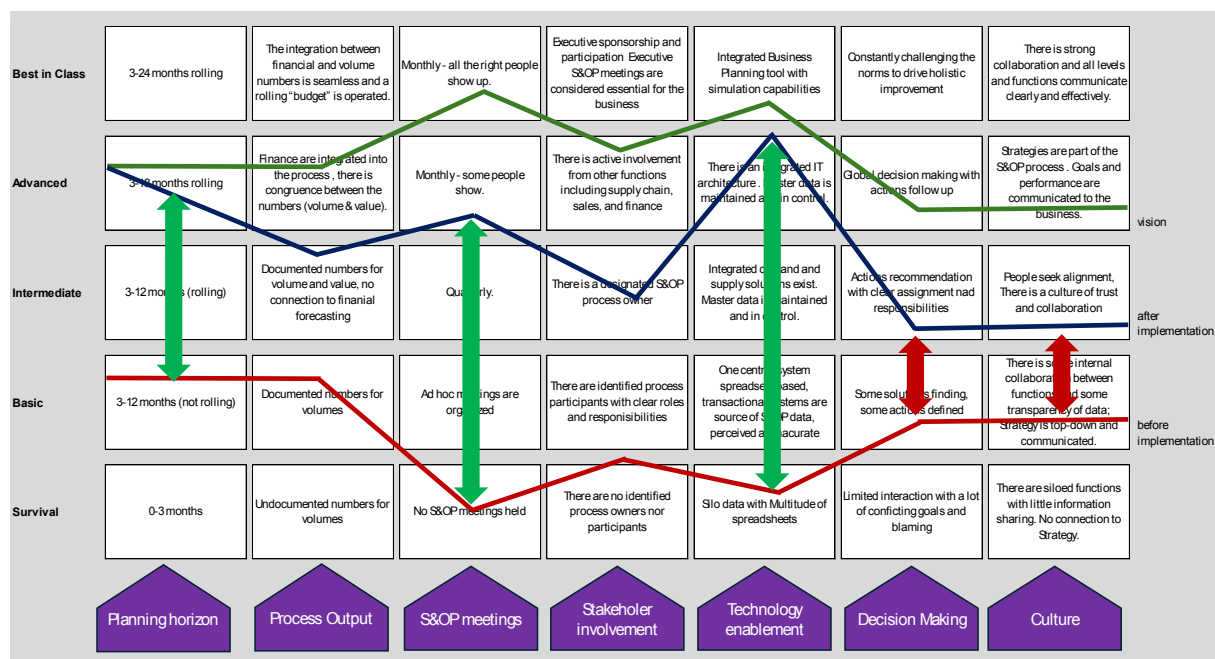
On Table 2 the actual timeline of the project is shown. As already indicated above, the project did not finish on time.

Table 2.*Actual project timeline with comparison*

Original Timeline	Actual Timeline	Project phase	Deliverables
2022 January	2022 January	Kick-off	High level requirements Project team
2022 March	2022 April	Preparation	To-be process map Mock up's
2022 June	2022 August	Demand planning	Capture forecast from customers Forecast review with countries Final demand plan signed off by head of sales
2022 July	2022 September	Inventory optimization	Plan for every part Safety stock levels
2022 September	2023 May	Supply planning	Finished goods supply plan Rough cut capacity planning Inventory level projection
	2023 September	Budgeting	Financial forecast
2022 December		S&OP fine tuning and transformation to IBP	Executive meetings

Source: own elaboration.

After closing the project, the Company conducted again the self-assessment for IBP process maturity level. The results are visible on figure 5.

**Figure 5.** IBP process maturity level after project closure.

Source: own elaboration.

Main progress was made in the technology enablement area. This indicates partial success of the project, specifically the project part focused on IT side of the process. Also in all other areas the progress is visible. Analyzing the results of the self-assessment, the Company stated that the foundations for IBP process were set. Yet the process did not yet transform into IBP as very little progress was noticeable in the three key areas differentiating S&OP process from IPB process, i.e. Stakeholder involvement, Decision making and Culture.

Even though from time line perspective the described project was not fully successful, yet the company learned a lot and continues journey towards fully working IBP process. Main changes implemented afterwards were personal changes in the executive team to gain more support for the process and reinforce global decision making. Next step was to drive the execution of the supply plan into the operational planning. This two steps in Authors view, will drive the IBP process in described Company towards full success.

Guidelines that the authors would give for similar projects, based on lessons learned from the described project are:

- gain executive support,
- use more agile approach: each step of the process should be split into: standard functionality delivery and customization delivery,
- clear responsibility for the data from day 1,
- wait with inventory process until the forecast accuracy is on acceptable level,
- start S&OP meetings even though not full process ready to gain engagement of the team and executives.

4. Conclusions

To summarize, the main reasons of not fully successful implementation of the process in the organization the authors would identify in the:

- lack of executive support,
- no strict execution of the S&OP supply plans,
- too big focus on technology and too low focus on process.

From a perspective, the change management process was the weakest point of the implementation. Although we can state that the 8 steps of Kotter's model were considered when starting the projects by creating sense of urgency, forming a guiding coalition and creating and communicating vision of change, yet during the implementation, the next steps of the change model were neglected. As stated before, first step of the project was not successful, the short term wins, even if existed, were not broader communicated, also the empowering was not fully

in place, mainly due to the lack of competence on the key users side. Mentioned problems were not addressed and lead to lost “momentum”.

The nature of the IBP process is cross functional dialogue resulting with global decision making. In order to reach this the S&OP meetings (or rather executive review meetings) should happen as soon as possible even if not all the data or steps of the process are ready. The Integrated Business Planning process is not a supply chain process it is the process connecting Supply Chain to other functions resulting in delivering the strategy and as such it should not just be used but should be driven by Executives.

Even though the above is known and described broadly in the literature, still, as in the example described in the paper, the companies try to have the S&OP process driven on supply chain side. According to the survey conducted in 2020 by Oliver Wight 65 percent of total 125 respondents failed involve their executives in the IBP process (Matthews, 2020). This according to Oliver Wight and many others must lead to a poor process not delivering expected results.

Effective implementation of S&OP requires organizational integration, standardized processes, and strong engagement from all departments. These factors contribute to enhanced operational, market, and profitability outcomes (Swaim, 2016). The most errors are due to separation IBP and S&OP in the day-to-day operations of many companies.

In summary, S&OP should be integral to the IBP process, providing alignment, visibility, accountability, and effective resource allocation while managing risks and leveraging technological tools to overcome challenges.

The conclusions drawn by the authors are generally in line with those drawn from the literature analysis. A methodical approach that offers companies a structured framework for key integration phases and milestones is essential for successful IBP implementation. Taking into account various critical success factors throughout the IBP implementation lifecycle helps minimize the risk of failure. To support this, a critical success factor framework can be applied within an integrated enterprise systems implementation model, particularly in collaborative manufacturing environments.

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BEHAVIOURAL DATA MINING FOR ORGANIZATION NETWORKS: OPTIMIZING KNOWLEDGE SHARING AND COLLABORATION

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Purpose: This study utilizes behavioural data mining techniques to analyze knowledge sharing and cooperation dynamics within the organizational network. The article focuses on understanding network composition through employee digital interactions, analyzing communication patterns and factors affecting effectiveness, developing a predictive behavioral model, and proposing strategic data-driven recommendations for knowledge management. The article aims to enhance organizational understanding and strategic decision-making.

Design/methodology/approach: By utilizing a mixed-method approach, this study seeks to leverage behavioural data for improved insights and choices. The method uses digital data mining to extract conversational, informational, and knowledge-consuming patterns from organizational platforms. Key actors and structural barriers are then identified through creating and analyzing organizational knowledge networks using social network analysis. Digital footprints are used in this method to comprehend the corporate knowledge network. Knowledge management principles and social network theory are part of the theoretical framework.

Findings: The study seeks to uncover knowledge brokers and bottlenecks, uncover patterns of behaviours associated with successful information sharing, and provide guidance for adaptation techniques aimed at improving collaboration and knowledge sharing inside organizations. The results will guide suggestions for process improvement by offering a data-driven understanding of the behaviours, important participants, and roadblocks in the knowledge network.

Research limitations/implications: The research acknowledges the fundamental limitations of concentrating on digital data. It also identifies significant implications to further the field of knowledge management by offering a basis for data-driven strategies and proposing significant avenues for future study, such as addressing ethical concepts.

Practical implications: This study offers strategies and insights from examining existing digital activities. They are context-specific, encourage collaboration, and enable adjustments to technology for better business outcomes.

Social implications: The article estimates significant effects on society, including improved innovation, problem-solving, inclusive knowledge access within organizations, positive public perception indirectly, and better Corporate Social Responsibility practices related to environmental issues.

Originality/value: The study applies behavioural data mining techniques to organizational knowledge management, offering a new approach to optimizing knowledge networks. It provides empirical evidence for using data-driven insights to enhance knowledge sharing and cooperation. By integrating qualitative insights with behavioural data mining and network

analysis, it offers a comprehensive understanding of organizational knowledge networks. Additionally, it provides practical guidance for researchers and practitioners.

Keywords: Behavioral data mining, organizational networks, knowledge sharing, collaboration optimization, social network analysis, machine learning.

Category of paper: Literature study publication.

1. Introduction

In the competitive landscape of the twenty-first century, according to Grant (2021), knowledge is a crucial asset for businesses, shifting from traditional structured processes to more informal communication methods due to digital tools and remote work. Behavioural data, generated through individual interactions, plays a vital role in enhancing knowledge-sharing practices within organizations (Alavi, Leidner, 2001). This data includes: email logs, instant messages, collaborative documents, and other forms of communication within the organization. Analyzing this data allows for the identification of hidden patterns and dynamics in knowledge flow, providing organizations with insights that were previously difficult to capture.

The research motif lies in the interest of understudying the increasing use of digital communication tools that generate vast amounts of behavioral data, often untapped for optimizing organizational performance. Despite the abundance of information, organizations struggle to use this data effectively to enhance collaboration and knowledge sharing. As organizations become more dependent on digital tools and networks, it is crucial to understand how these tools facilitate or hinder knowledge exchange. This study explores how data mining can enhance knowledge-sharing practices within organizations and predict outcomes of collaborative efforts, addressing a gap in the existing literature on these topics. The findings could significantly benefit organizations that utilize digital communication tools like email, Slack, and Microsoft Teams for internal collaboration. The study analyzes data from these platforms to identify temporal trends and behavioral patterns within the organization. The scope of this study is limited to internal organizational networks and does not address external collaboration (such as interactions between organizations or with customers). The findings will be contextualized to the tools and platforms used within the organizations under investigation.

1.1. Importance of Knowledge Sharing in Organizations

Effective knowledge sharing enhances collaboration, problem-solving, and decision-making among employees, which in turn boosts an organization's collective intelligence and innovation. This is essential for businesses aiming to remain creative and competitive in a rapidly evolving global landscape. (Nonaka, Takeuchi, 1996). Knowledge sharing can occur in both formal and informal settings within organizations. Formal mechanisms of knowledge

sharing according to Davenport & Prusak (1998), include structured processes such as: training programs, workshops, and knowledge management systems (KMS), where knowledge is deliberately transferred between individuals or groups. Informal knowledge sharing, however, often happens through casual conversations, emails, and social interactions among employees. Informal networks are often more effective in facilitating knowledge exchange compared to formal ones. According to Muhammed & Zaim (2020), informal interactions in the workplace foster a comfortable atmosphere for employees to share valuable insights that aid in problem-solving and creativity. As also illustrated in Figure 1, effective information sharing relies on company culture, trust, and social dynamics, as employees are more inclined to contribute when they feel valued and supported, unlike in competitive or privacy-focused environments.

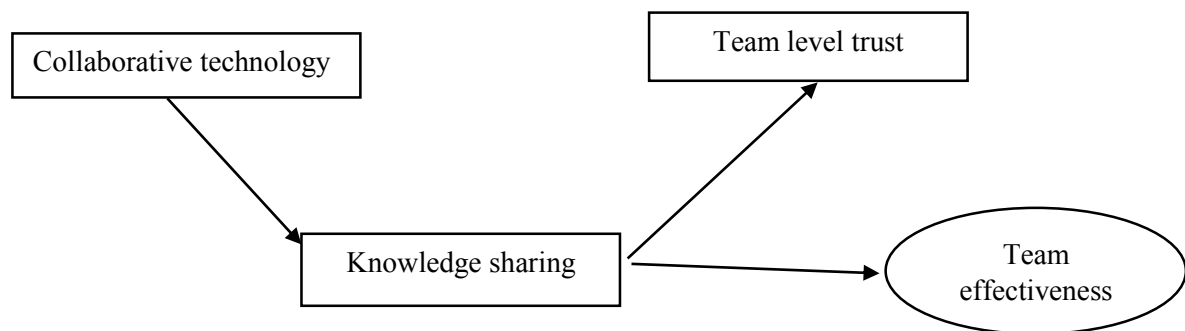


Figure 1. Illustration of the preliminary virtual team effectiveness: The role of knowledge sharing and trust in an organization.

Source: (illustration by the author based on Alsharo et al., 2017).

Digital technology has transformed the sharing of both formal and informal information through tools like email and collaboration platforms, enhancing communication and increasing the volume of behavioral data in organizations, as opined by McAfee et al. (2012). This shift is crucial for organizational performance, innovation, and learning. In summary, the importance of knowledge sharing in organizations cannot be overstated. It is integral to organizational learning, performance, and innovation. As organizations continue to adopt digital communication tools, understanding how knowledge flows within these networks and how it can be optimized using behavioral data mining is becoming a central research priority.

1.1.1. Organizational Knowledge Sharing

Effective knowledge management is crucial for businesses navigating a competitive landscape, with knowledge sharing occurring through explicit and tacit forms. While explicit knowledge is easily documented, tacit knowledge, which is more personal and complex, has been shown to significantly enhance innovation and problem-solving within organizations. (Nonaka, Takeuchi, 1996). Figure 2 breaks down the knowledge process of tacit and explicit knowledge on organizational impacts, given that research by Grant (2021) has shown that tacit knowledge sharing is often more valuable for organizations, driving innovation and enhancing problem-solving capabilities. However, its intangible nature makes it difficult for organizations to formalize and disseminate effectively.

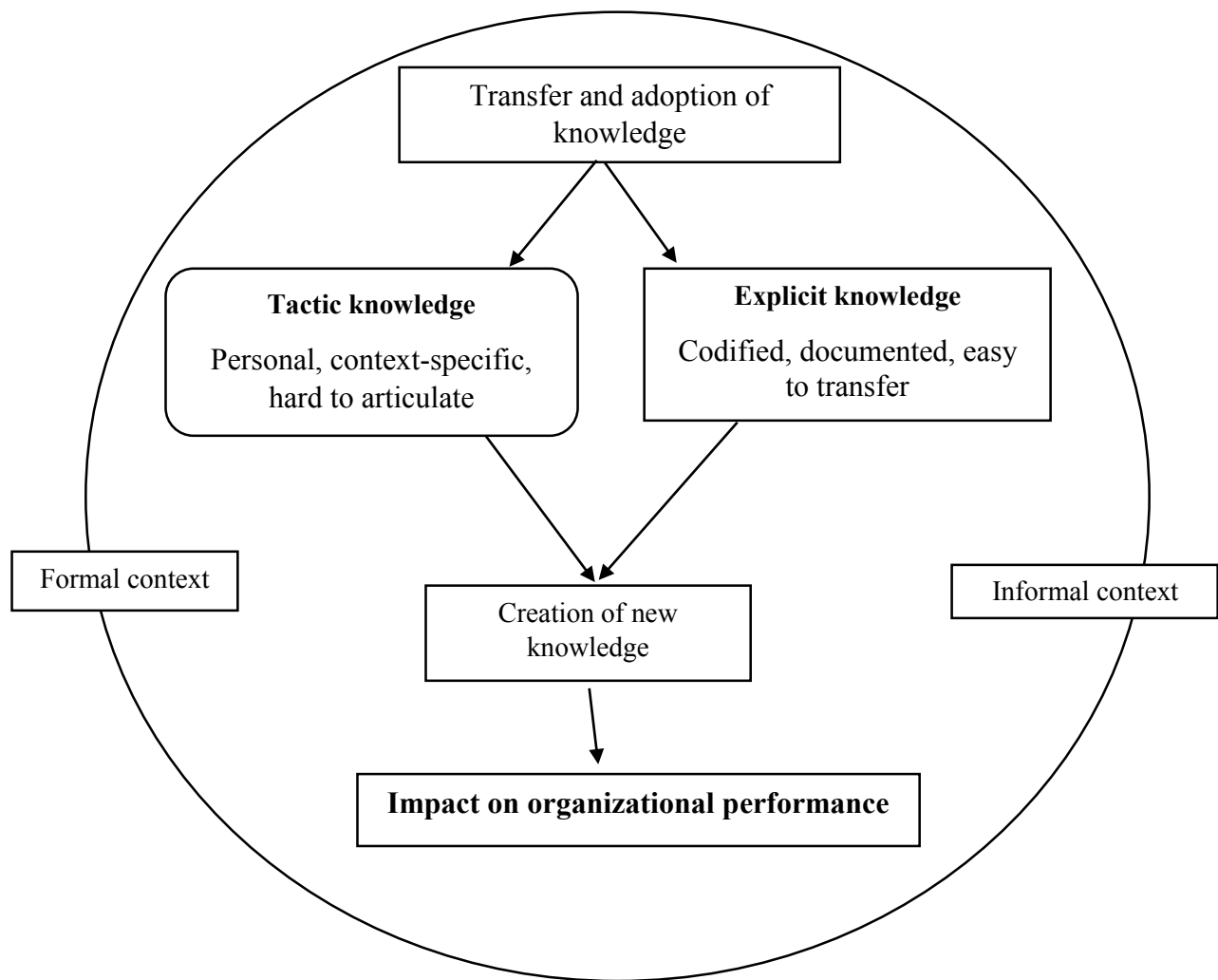


Figure 2. Knowledge processes of tacit and explicit knowledge.

Source: (Illustration by the author, 2025).

The performance of an organization is directly impacted by the efficient exchange of knowledge. Effective knowledge-sharing procedures enhance innovation, productivity, and decision-making in organizations, as highlighted by Muhammad and Zaim (2020). However, as Figure 3 also illustrates, the process is complex and influenced by factors such as organizational culture, beliefs, and available technology, with research indicating its link to increased market share and consumer satisfaction (Davenport, Prusak, 1998).

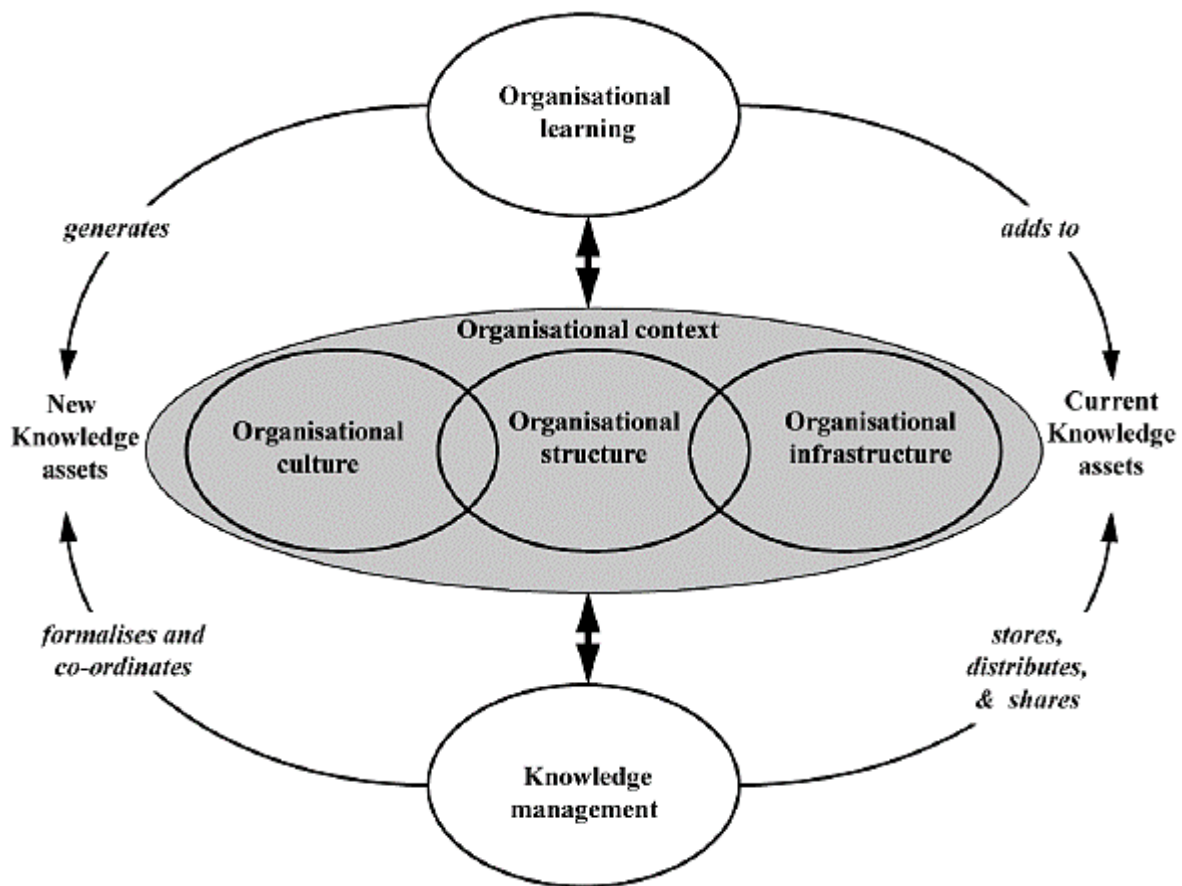


Figure 3. The relationship between organizational learning and knowledge management.

Source: (illustration by the author based on Stonehouse and Pemberton, 2000).

1.2. Collaboration Networks and Social Capital

Collaboration networks in organizations enhance the sharing of skills and expertise by leveraging social capital, which Table 1 highlights, which also includes trust and information access, to facilitate effective collaboration and innovation (Nahapiet, Ghosal, 1988; Garcia-Sanchez et al., 2019). Recent studies by Reus et al. (2023) indicate that individuals in brokerage positions within these networks are more adept at improving the quality of information shared by bridging instructional gaps.

Table 1.

Forms of social capital and their influence on knowledge sharing

Dimension of social capital	Definition	Influence on knowledge sharing
Structural	Network ties and patterns of connection	Provides access to diverse knowledge sources
Relational	Trust and norms among members	Encourages open sharing and reduces knowledge hoarding
Cognitive	Shared language, goals, and mental models	Enhances understanding and relevance of shared knowledge

Source: (table by the author, 2025).

Remote individuals within a network may struggle with communication, hindering innovation, which highlights the need for an inclusive environment that encourages collaboration. As highlighted by Lee & Han (2024), a learning-oriented culture, combined with strong social capital, enhances knowledge sharing and overall organizational performance by fostering mutuality and shared goals. Behavioural data knowledge management (BDKM) emphasizes the importance of behavioral data, like interactions and decision-making patterns, in understanding and improving knowledge management within organizations. By analyzing how information flows through formal and informal networks, BDKM helps streamline knowledge sharing and enhances organizational efficiency.

Formal roles in the organizational hierarchy, managers, supervisors, and department leads, play a central role in decision-making and directing knowledge flow, as depicted in Figure 4. Guo et al. (2023), confirms informal roles, such as connectors, influencers, and knowledge brokers, often emerge based on individual actions, interactions, and personal networks these individuals may not have formal authority, but their behavior and interaction patterns allow them to facilitate or hinder knowledge sharing within the organization. Organizations can leverage behavioral data analysis to identify key players in their collaboration networks and uncover knowledge gaps. By examining interaction patterns, they can enhance data sharing practices and promote effective knowledge exchange among staff.

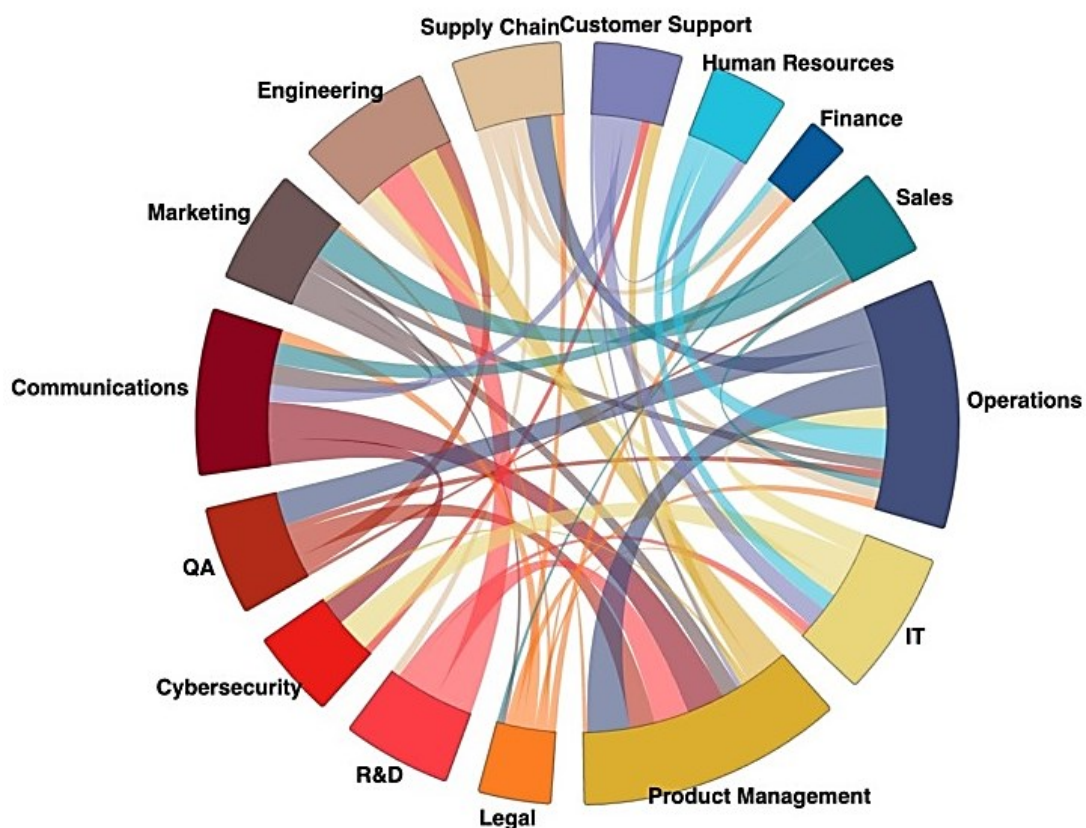


Figure 4. Illustration of the dynamics of organizational hierarchy collaboration networks.

Source: The Organizational Network Analysis (ONA) diagrams (2025).

Behavioural data can help improve organizational collaboration by identifying gaps in knowledge exchange and assessing the effects of information sharing on decision-making. Guo et al. (2023). Helms & Buijsrogge (2006) opined those inefficiencies in information flow often led to problems in cooperation networks, particularly when gatekeepers become overwhelmed, hindering effective knowledge sharing. By analyzing information flow and identifying delays, organizations can pinpoint overworked employees and assess their role in key interactions, as well as detect barriers to knowledge sharing stemming from both structural and behavioral factors. This approach helps in improving knowledge management by addressing obstacles that hinder effective collaboration. Using behavioral data analysis, organizations can take proactive steps to address these bottlenecks by redistributing knowledge flows or by encouraging behaviors that foster collaboration and efficient information transfer, as highlighted by Borgatti & Halgin (2020).

1.3. Behavioral Data in Organizational Settings

Behavioral data refers to the information about roles, interactions, and communication within an organization, largely generated by digital technologies. Analyzing this data can reveal communication patterns and challenges, highlighting issues like isolated individuals in the network that may hinder information sharing according to Wang et al. (2019). Understanding the emotional tone of communication is essential for predicting team cooperation and outcomes, as positive emotions often lead to higher engagement and better teamwork. Teams that communicate positively tend to perform better since members are more likely to rely on each other and collaborate effectively, as Figure 5 shows a clear flow of the behavioural data mining process, highlighting key areas and interchanges.

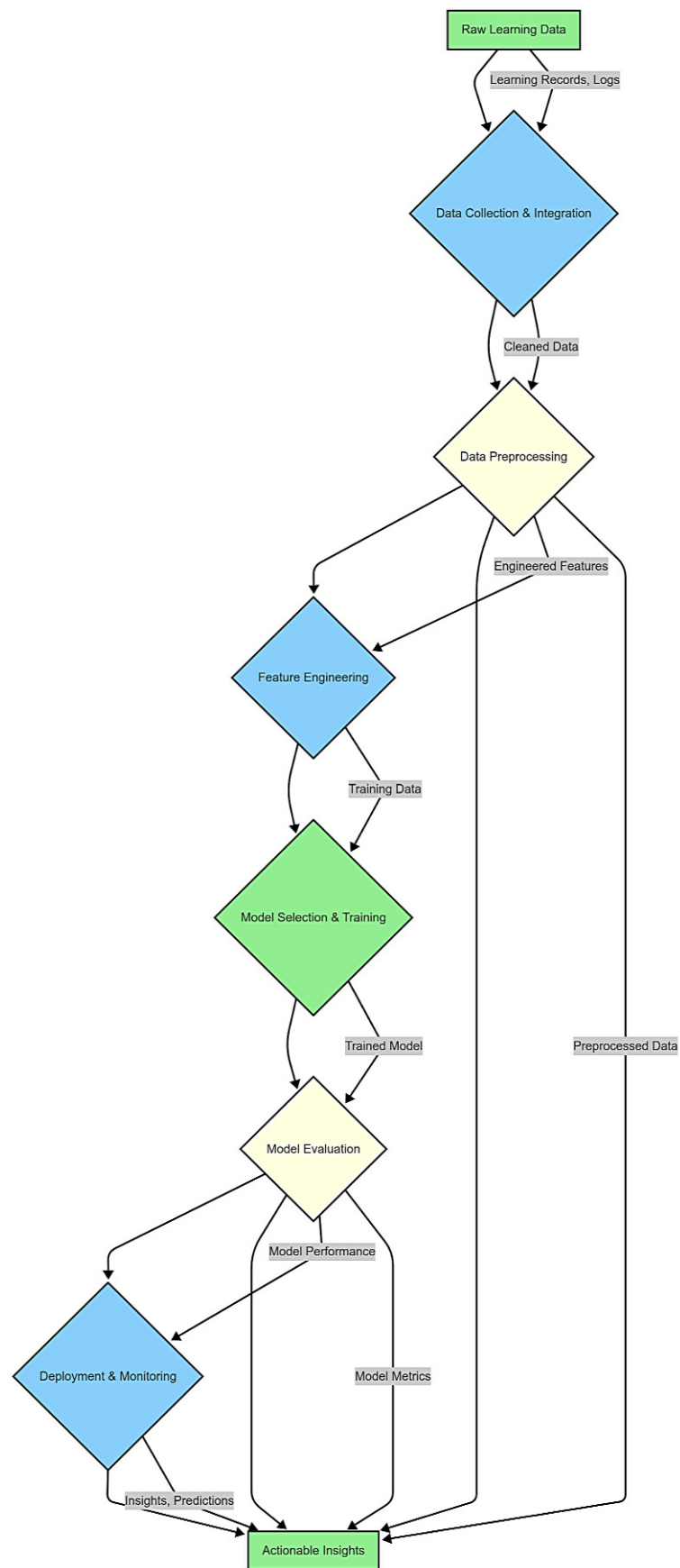


Figure 5. A behavioral data mining and processing flowchart.

Source: (illustrated by the author, 2025).

As described in Table 2, the various behavioural data types can be utilized to better understand and enhance knowledge sharing within an organization. These data types are derived from employee interactions. It classifies the information, explains its meaning, and discusses how it might be used in a knowledge-sharing setting.

Table 2.

Types of behavioral data and their use in organizational research

Type of behavioral data	Description	Application in knowledge sharing
Communication patterns	Frequency and channels of communication (e.g., email, meetings, instant messages)	Identify key influencers, and collaboration bottlenecks
Response times	Time taken for individuals to respond to messages or requests	Assess the responsiveness of teams and departments
Sentiment	Emotional tone of communication	Predict collaboration success, improve team dynamics

Source: (table by the author, 2025).

2. Methodology

The study employs a mixed-method approach to strengthen the validity and reliability of the findings using the data triangulation covered in subsequent subcategories.

2.1. Research Design and Strategy

A discovery sequence mixed-method design was utilized to collect and analyze quantitative data. The quantitative phase involves behavioural data analysis from digital platforms to map and examine the organizational knowledge network's structure via social network analysis. To understand subject experiences better, a more comprehensive insight into the study problem was undertaken.

2.1.1. Data Sources

Quantitative data for the study was gathered from various digital platforms used within organizations, including email logs showing communication patterns, project management tools like Asana and JIRA for task details and collaboration insights, and associate platforms like Slack and Microsoft Teams for channel usage and information flow. SharePoint, Confluence, and similar systems offer insights on document usage, changes, sharing, and contributions, showing the utilization of formal knowledge assets.

2.1.2. Data Collection

The following data were gathered for the study:

Digital interaction data: This covered how often and how strongly people interacted with one another on different digital platforms. The encounter was recorded using this "pre-physical behavior data" before any in-person contacts.

Communication pattern: Data on people's digital communication methods showed their distinct conversational philosophies.

Emotional ratings: Information on emotional indicators or feelings was gathered via online conversations.

Network Matrix: Information was gathered to create a matrix that included the digital interaction network's structure and features, including the degree of interpersonal connection.

Historical behavior data: To serve as a foundation for forecast model training, a broad collection of historical behavior data was gathered.

Collecting data meticulously was essential to understanding collaborative dynamics within the organizational knowledge network.

2.1.3. Data Processing and Analysis

The analysis of the data acquired followed a comprehensive multi-step procedure, principally making use of the methods of supervised machine learning to generate actionable insights.

- 1. Data Preprocessing and Feature Engineering:** Initially, raw digital interaction data was preprocessed, converting communication logs into structured data. Network metrics such as centrality, density, and clustering coefficients were then calculated, providing insights into the organizational knowledge network structure. Communication patterns, volume, and emotional ratings were assessed to create features for future machine learning models.
- 2. Defining Outcome Variables:** The study established outcome factors to predict team performance, including quantitative measures like project success, efficiency metrics, and performance ratings. Factors such as onboarding speed and technology adoption rates were used to assess knowledge transfer effectiveness, forming the "ground truth" for supervised learning.
- 3. Supervised Machine Learning Model Training:** Various supervised machine learning techniques were used for model training with finalized features and predetermined outcome variables. The training involved providing historical behavioral data and engineering facilities to teach algorithms the complex relationships between digital contacts, communication styles, emotional phases, and real team performance or knowledge transfer outcomes. Regression and classification models were employed to predict both continuous outcomes, such as a display score, and categorized outcomes, such as team performance or knowledge transfer success.
- 4. Feature Selection Techniques:** The model's effectiveness was enhanced by carefully selecting the most relevant traits from various network measurements and emotional assessments, reducing noise and preventing overfitting to ensure focus on significant behavior indicators.

- 5. Model Performance Evaluation:** The metrics assessed the performance and dependability of trained models, mainly through accuracy and misses. Misses were crucial when all instances of a specific outcome mattered. These evaluations ensured the models' robust future-predicting abilities before their deployment.

The processing of the data showcased supervised machine learning in action, emphasizing meticulous analytical methods. It illustrates the creation of network measurements and emotional evaluations from raw digital interaction data, and also establishes outcomes for knowledge transfer and team performance, while training regression and classification models.

3. Findings

3.1. Behavioural Data Mining Models

This section explains the data mining models developed to analyze the organizational knowledge network. These models are crucial for providing insights into knowledge sharing and cooperation adaptation during the data collection and preparation stages.

3.1.1. Network Construction from Behavioural Data

This study created a knowledge network within an organization by studying how individuals interact digitally before even meeting in person. Think of it this way: each individual is a dot (node) connected by lines (edges) based on their digital interactions. The frequency with which they communicate using different digital tools and platforms determines the strength of these connections, or the "weight" of lines as Wasserman & Faust (1994) described. For instance, email exchanges between two people will determine one's advantage in the email network; co-participation and shared tasks will impact the project cooperation network; engagement with documents weighs the edges in the documents access network. Different network layers can be created for various interactions, such as separate networks for email communication, project collaboration, etc. According to Szell et al. (2010), analyzing these layers individually or using multiple network analysis approaches can help understand how different interaction modes shape the organization's knowledge network overall. Understanding the organization's knowledge flow structure is based on this network.

3.2. Identifying Key Influencers and Bottlenecks

After creating the knowledge network, various social network analysis matrices were used to identify key accomplishments and challenges. As Scott (2024) emphasized, people with many direct connections, known as hubs, play a vital role in communication networks. Those with intermediate centrality connect different subgroups, facilitating information flow. People with high eigenvector centrality are influential and connect with other significant individuals. Targeted interventions were used to leverage these key individuals' central positions to promote information sharing within the network. Network nodes with restricted information flow were pinpointed by identifying individuals or groups connecting dense groupings and lacking central links, which is a bottleneck. Figure 6 also depicts communication bottlenecks, and recognizing such barriers was essential for designing interventions to boost network connectivity and knowledge sharing, visually identified using network visualization tools.

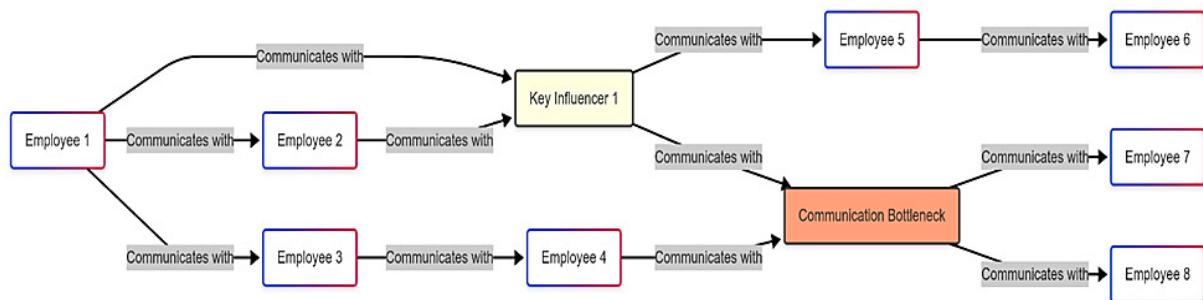


Figure 6. illustration showing the connections between employees in an organization, highlighting key influencers and communication bottlenecks.

Source: (illustration from the researcher, 2025).

3.3. Sentiment and Communication Analysis

Communication content on the network provided insights into collaboration and knowledge. Text data underwent NLP analysis, including information from communication platforms and emails when ethically appropriate. According to Liddy (2001), a key component of behavioral analysis is examining the emotional tone of communication. Negative emotions can imply obstacles to sharing information, while positive emotions encourage cooperation. Emotional states of project teams or communication channels may unveil dynamics for time series analysis. In communication analysis, subjects, queries, and responses are examined to identify main topics and knowledge domains using subject modeling technology. According to Blei et al. (2003), analyzing question and answer flows, knowledge gaps, and subject-matter specialists can be identified, along with assessing accessibility and inclusivity in knowledge-sharing through language variety in group conversations.

3.4. Machine Learning for Predicting Collaboration Outcomes

Using machine learning methods, future models for cooperative outcomes can be developed based on behavior attributes as outlined by Bishop (2006). Project success is measured by stakeholder satisfaction, budget management, and on-time completion. Innovation output is gauged by the development of new concepts, patents, and new products/services. The team's work was evaluated based on reviews and outcomes, and knowledge transfer progress was measured using technology rates and onboarding speed. Computer programs, including regression and classification models, were trained with historical behavior data to forecast outcomes utilizing network measures, trends, and emotions. Facilities selection methods were employed to improve behavior predictions for collaborative results. Model performance was assessed using metrics like recall and accuracy to identify individuals or groups with poor collaboration potential and suggest remedies based on behavior patterns.

4. Discussion

This section highlights research findings, discusses their implications on organizational design and management, and acknowledges the organizational knowledge network in behavioral data mining applications.

4.1. Implications for Organizational Design and Management

This shows how businesses can structure, manage knowledge assets, and engage in activities.

- Mapping and analyzing organizational knowledge networks using behavioural data helps managers understand interaction patterns and knowledge flow. This informs decisions on collaborations, placements, and structure modifications to enhance knowledge exchange. Identifying key knowledge brokers and addressing structural gaps are crucial for optimizing relationships among groups.
- Insights from behavioural data mining can drive more tailored and successful knowledge management interventions for organizations, helping them adjust tactics to their unique knowledge network needs. For example, focusing training on communication and conflict resolution for teams showing negative communication patterns can be beneficial. Taking further action, like team coaching or procedure adjustments, can be based on machine learning predictions of potential project failure due to cooperation issues.

- By understanding factors for successful collaboration and innovation from a machine learning model, organizations can design platforms and rules to enhance creativity through cross-functional contact and various channels. Fostering interactions in communities of practice around specific knowledge areas discovered through subject modeling can advance innovation.
- Identify individuals with strong knowledge-sharing and networking skills for leadership roles or relevant projects. Help those who are isolated in the network by facilitating connections and integration strategies.
- Behavioural data acts as an objective measure to evaluate the effectiveness of a data mining knowledge management initiative. Monitoring changes in network density, emotion scores, communication patterns, and centrality metrics over time can help assess the intervention's impact on promoting information sharing and collaboration, with future collaborative outcomes serving as a key performance metric for the organizational knowledge network.

At the end of the day, organizations benefit from this approach by gaining a data-driven framework to enhance knowledge management, optimize team structure, allocate resources effectively, and implement targeted interventions through behavioural data and analytics.

4.2. Limitations and Critical Considerations

Despite behavior data mining's impressive capacity to understand and personalize the organizational knowledge network, it is important to recognize the various restrictions and critical considerations in place.

- Data bias and perfection are evident in digital platform data, restricting analysis without informal contact or implicit knowledge. Incomplete networks may result from this limitation, influenced by individual preferences, technical expertise, or corporate policies, skewing tool patterns and network representation.
- When collecting and analyzing behavioural data, it is essential that Organizations address privacy and ethical concerns. They should implement strong protection measures, obtain consent from employees, and maintain transparency. Additionally, they must be cautious about misinterpreting or misusing the data.
- Analyzing behavioral data can highlight strong associations, but establishing clear causation can prove challenging due to complex underlying factors, necessitating careful evaluation and intervention planning.
- Knowledge networks in organizations constantly evolve due to changes like personnel, projects, or structure, making continuous monitoring crucial for accuracy.
- Data mining can uncover complex patterns, but translating them into actionable insights for business improvement and intervention creation requires clear communication and a deep understanding of organizational context and technical analysis.

- "Human Factors" such as faith, culture, inspiration, and social mobility influence cooperation and knowledge exchange. Behavioural data provides insights, but cannot capture all the nuances of human interaction.

In organizational contexts, addressing ethical and crucial concepts is key for successful behavioural data mining applications. A well-rounded strategy blending data-operated insight with qualitative understanding and moral concepts is essential for maximizing information sharing and collaboration adaptability.

4.3. Roles and Importance of Artificial Intelligence

In addition to highlighting the important role of AI, particularly in real-world applications in organizations, the article focused on the systematic development of organizational knowledge networks and analytical abilities. AI played a crucial role in this work by converting unprocessed behavioural data into insightful knowledge, especially supervised machine learning techniques like regression and classification models. This study highlights how AI is crucial for implementing solutions in businesses by excelling in identifying patterns and generating insights in complex datasets. AI's machine learning algorithms excel at uncovering intricate relationships among network measurements, communication patterns, emotional ratings, and collaboration solutions, allowing for the detection of subtle behavioral cues that manual analysis may miss. The study emphasized AI's predictive and prescriptive capabilities by using prediction models to anticipate future collaboration problems and provide data-driven remedies. Organizational processes are transformed using this AI approach because problems are tackled early on, and this provides scalable and effective analysis. When AI and human capital management are combined, organizations can make effective data-driven decisions, as evidence-based insights are available, thereby reducing reliance on anecdotes. Machine Learning's (ML) recurrent nature ensures that continuous model improvement is made. This demonstrates AI's critical role in organizational growth through continuous learning by enabling more effective solutions and precise projections based on behavioral data and intervention outcomes.

The design of the study acknowledged that behavioral data alone was not enough. In order to improve organizational cooperation, information sharing, and future forecasting, deep analysis was made possible in large part by artificial intelligence (AI). It would be extremely difficult to provide intelligent answers in a dynamic situation without artificial intelligence.

5. Summary and Recommendations

The conclusion section of the study provides key findings and practical suggestions for companies looking to utilize behavioural data mining. It also includes adoption recommendations, primary contributions, research significance assessment, and suggestions for future studies.

5.1. Strategic, Operational, and Technical Recommendations

The study's conclusions have led to the following recommendations being made:

1. **Strategic Recommendations:** Organizations should adopt a data-led knowledge management approach, integrating data analytics into their strategy. Also, create a culture of moral consciousness and data literacy, emphasizing ethical use of behavioral data and promoting trust. They can also align knowledge management objectives with professional goals to enhance collaboration and support organizational objectives.
2. **Operational Recommendations:** Use ongoing network monitoring to analyze changes in network structure, communication styles, and collaboration efficacy. Craft targeted interventions based on communication patterns, key players, and obstacles. Incorporate network insights into performance management for rewarding knowledge sharing and cooperation. Encourage knowledge repositories and collaborative platforms through digital tools and user-friendly integration.
3. **Technical Recommendations:** Invest in a robust data infrastructure for data collection and analysis. Implement technology to collect, store, process, and analyze behavioural data from various digital platforms. Make use of advanced behavioral data mining models, such as machine learning and network analysis. Develop internal expertise in network analysis and data science through hiring or training.

Implementing these recommendations can enhance organizational performance and flexibility by optimizing knowledge flow in today's digital world.

5.2. Guideline for Organizational Adoption

Organizations looking to adopt a behavioural data mining approach for their knowledge networks should consider these key guidelines: Start with clear objectives, engage stakeholders on data privacy, initiate pilot projects, iterate the approach, blend quantitative and qualitative data, focus on actionable insights, and continuously evaluate and adapt strategies.

5.3. Summary of Key Points

This study identifies behavioural data mining's role in understanding and modifying organizational knowledge networks. Insights from the study include: analyzing behavioural data from digital platforms helps create and analyze organizational knowledge networks; social

network analysis of these networks uncovers significant influences on information transfer; studying communication and emotions reveals interaction quality; machine learning algorithms predict support outcomes based on behavior patterns; integrating quantitative and qualitative data provides a comprehensive view of knowledge sharing dynamics.

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THE IMPORTANCE OF OPEN INNOVATION FOR THE DEVELOPMENT OF CIRCULAR ECONOMY

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Purpose: The importance of OI for the development of CE is a relatively new field of research. The purpose of the study is to present the possibilities of supporting the circular economy through the adoption of the Open Innovation concept in the enterprise.

Design/methodology/approach: A thesis was formulated assuming that the adoption of the Open Innovation paradigm is conducive to the implementation of the principles of the circular economy in the enterprise. The author's considerations are based on literature studies and a review of the results of selected secondary research. The basic research method is *desk research* (analysis of existing data).

Findings: The author presented the possibilities for supporting the circular economy through Open Innovation activities, with an emphasis on cooperation between stakeholders and co-creation. The analysis of the results of selected existing studies allowed the author to confirm the thesis.

Research limitations/ implications: A limitation of the study of the importance of OI for the development of CE is the concentration of considerations at the level of enterprises.

Practical implications: The study promotes managers' focus on OI processes for the purpose of accelerating the transition to CE, indicating the preferred options for activities.

Social implications: The inclusion of recommendations by leaders/managers should have a positive impact on the development of the circular economy.

Originality/value: The results of the analysis have cognitive value in the context of drawing attention to the possible synergy between OI and CE. Managers were offered recommendations for a strategic approach to the utilization of OI for the development of CE.

Keywords: Open Innovation, Circular Economy, cooperation, co-creation.

Category of paper: general review; research paper.

1. Introduction

The 5th Congress of Management Sciences of TNOiK - The Scientific Society for Organization and Management (Warsaw, 22-23 May 2025), organized in the year of the 100th anniversary of the founding of this organization, prompted the author to reflect once again on

the achievements of Karol Adamiecki (1866-1933), a professor of the Warsaw University of Technology and the first director of the institution, formerly known as the Institute of Scientific Organization (Instytut Naukowej Organizacji). This outstanding pioneer of management sciences promoted the principles of scientific organization, emphasizing, among others, the importance of their implementation in order to counteract “waste of capacities and resources within manufacturing plants” (Adamiecki, 1932, p. 34).

One of the most important contemporary concepts promoting and developing the care for efficient resource management is the so-called **Circular Economy** (CE), the principles of which are implemented not only at the level of enterprises, but also cities, regions, and the national economy. Circular Economy is an alternative model that can help reduce environmental impacts and build a more sustainable future (Geissdoerfer et al., 2023). The development of circular economy has become a strategic priority of the EU on the path towards achieving the Sustainable Development Goals (UN, 2015), and in particular goal 12: responsible consumption and production. It is therefore advisable to support activities conducive to transformation towards a circular economy at all the above-mentioned levels. These activities are associated with efforts to eliminate barriers and activate innovative processes leading to innovation in the area of circular economy.

The concept of **Open Innovation** (OI) promotes two-way interactions and inter-organizational cooperation, thereby encouraging the acceleration of internal innovation processes. Open Innovation has been the subject of broad interest of theorists and researchers for over twenty years, but it is presented less frequently in conjunction with the concept of circular economy.

The research problem, narrowed down in the study to the level of enterprises, focuses on the question of whether the adoption of the Open Innovation concept has an impact on the transformation towards a circular economy. A thesis was formulated which assumes that the adoption of the Open Innovation paradigm is conducive to the implementation of the principles of the circular economy in the enterprise.

The **purpose of the study** was to determine the possibilities of supporting the circular economy through the implementation of the Open Innovation concept in the enterprise.

On the path to achieving this purpose the author presented the essence and aspects of the circular economy, the barriers to the transition to CE, as well as the assumptions and the framework of the Open Innovation concept. The author's considerations are based on literature studies and a review of the results of selected secondary research. The basic research method used in the study is *desk research* – analysis of selected existing scientific reviews and bibliometric analyses. In the conclusion of the study the author presents her own approach to the examined problem, leading to recommendations for managers interested in the circular economy in light of the ongoing ecological transformation. Recommendations for further research and analyses are also included.

2. The concept of the circular economy

Circular Economy is the subject of interest of theoreticians and scientific researchers, as well as business practitioners. For firms, CE implies the transforming production, supply chains and linear models to circular ones, transforming waste and excess resources into new materials and products (Blomsma, Brennan, 2017). Unlike the linear economy model where products “single-use” means a “take-make-dispose” pattern, CE ensures products circularity in a value chain (Bonsu, 2020), promoting the utilization of waste as useful inputs in the production process. This allows for avoiding waste and extending the lifecycle of resources.

Examples of definitions of the circular economy (Table 1) focus on sustainability and resource efficiency.

Table 1.
Selected definitions of the Circular Economy

Author	Definition of the Circular Economy
Ellen MacArthur Foundation (2013, p. 25)	The term ‘circular economy’ denotes an industrial economy that is restorative by intention and design. In addition to meeting current demand/consumption needs, a circular economy also actively invests in improving resource systems and increasing their resilience to ensure their continuing availability in the future.
Pichlak, Kruczek (2017, p. 22)	Circular economy is “an economic system characterized by the principle of sustainable development and less dependent on depleting natural resources than traditional economies, through the mechanism of recycling of waste constituting an output of the system”.
Korhonen et al. (2018, p. 547)	CE is a sustainable development initiative with the objective of reducing the societal production-consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows to the linear system. CE promotes high value material cycles alongside more traditional recycling and develops systems approaches to the cooperation of producers, consumers and other societal actors in sustainable development work.
Alhawari et al. (2021 p. 13)	CE is the set of organizational planning processes for creating, delivering products, components, and materials at their highest utility for customers and society through effective and efficient utilization of ecosystem, economic, and product cycles by closing loops for all the related resource flows.
Kirchherr et al. (2023, p. 7)	The circular economy is a regenerative economic system which necessitates a paradigm shift to replace the ‘end of life’ concept with reducing, alternatively reusing, recycling, and recovering materials throughout the supply chain, with the aim to promote value maintenance and sustainable development , creating environmental quality, economic development, and social equity, to the benefit of current and future generations. It is enabled by an alliance of stakeholders (industry, consumers, policymakers, academia) and their technological innovations and capabilities.

Source: own compilation.

As far as the pursuit of a uniform definition of CE is concerned, it can be determined – based on an analysis of 221 definitions of Circular Economy - that contemporary researchers see sustainability as the main objective of CE. According to researchers, the transformation towards a circular economy is based on a **broad alliance of stakeholders**, including producers, consumers, decision-makers and scientists (Kirchherr et al., 2023). The cited researchers formulated the definition of CE (Table 1) adopted for the purposes of the study.

The successful implementation of this closed-loop system requires fundamental changes in the firm product design and manufacturing processes as well as in management practices (Ferasso et al., 2020). Enterprises transitioning from a linear economy to a circular economy are transforming their business models, taking into account the principles of CE.

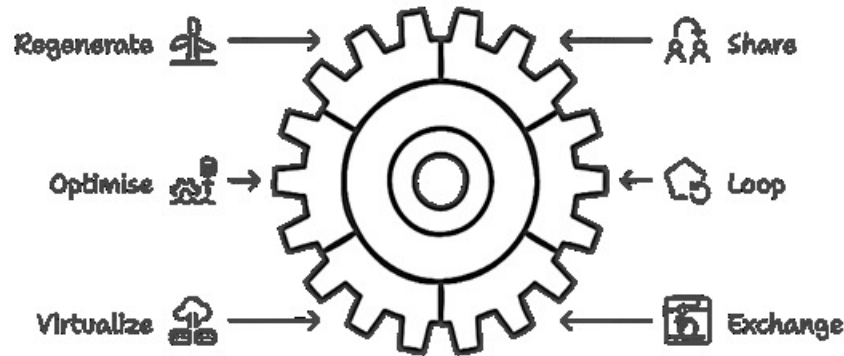


Figure 1. ReSOLVE framework.

Source: own compilation on the basis of: Kyrö (2020), with the use of the Napkin AI application.

Numerous models of activity paths within the Circular Economy, also referred to as CE business models, have been presented in the literature of the subject. In essence they refer to the principles and processes of value creation, which covers the foundations of a business model. The ReSOLVE framework, developed by the Elie McArthur Foundation (2015), covering six key actions (Figure 1) is the most commonly used CE model according to the researchers (Kyrö, 2020). The elements of the ReSOLVE framework are shown in Table 2.

Table 2.
Selected elements of the ReSOLVE framework

ReSOLVE FRAMEWORK
Regenerate signifies the shift to renewable energy and materials. It is related to returning recovered biological resources to the biosphere.
Share actions aim at maximizing utilization of products by sharing them among users. It may be realized through peer-to-peer sharing of private products or public sharing of a pool of products; sharing means also reusing products as long as they are technically acceptable to use (e.g., second-hand), and prolonging their life through maintenance, repair, and design enhancing durability.
Optimise actions are focused on increasing the performance/efficiency of a product and removing waste in the production process and in the supply chain; they may also be related to leveraging big data, automation, remote sensing, and steering; what is important is that optimization does not require changing the product or the technology.
Loop actions aim at keeping components and materials in closed loops; higher priority is given to inner loops.
Virtualize actions assume to deliver particular utility virtually instead of materially.
Exchange actions are focused on replacing old materials with advanced non-renewable materials and/or with applying new technologies (e.g., 3D printing).

Source: Lewandowski, 2016.

The implementation of principles of CE in an enterprise requires the transformation of processes from a linear approach to a circular approach, which often requires innovations in products and business processes, as well as incurring certain expenses. The benefits for the enterprise and the environment, such as improved environmental, market and social efficiency, especially in the longer term (Castro-Lopez et al., 2025), justify counteracting the barriers

encountered in the transition to CE. External barriers are mainly related to supply chain management and institutional complexity, while internal barriers relate to enterprise-specific constraints. The following barriers for Circular Economy are mentioned (Dorrego-Viera, Urbinati, Lazzarotti, 2025):

- **contextual** - referring to the structural and cultural environment in which enterprises operate; one challenge in the external environment are complex supply chains, in which production and consumption take place in many countries; one internal barrier is structural rigidity wherein organizational hierarchies and constraints suppress flexibility and innovation, which are crucial for the adoption of CE; market and cultural resistance as well as risk aversion hinder progress towards CE (Jaeger, Upadhyay, 2020);
- **economic** - relating to financial challenges associated with the implementation of CE (Kirchherr et al., 2018); high initial costs are a significant barrier, including investments in reconstruction, relocation of infrastructure, construction of new infrastructure and retraining of personnel (Salvador et al., 2022; Kirchherr et al., 2018);
- **technical** - resulting from the lack of skills, knowledge and technologies required for the transition to CE: the lack of information on the design and production of products hinders the development of CE-compliant products; one significant barrier is the quality compromise, as enterprises are concerned that prioritizing environmental issues over efficiency may reduce product quality.

According to researchers, technological limitations are among the most important challenges faced by enterprises transitioning to CE (Dorrego-Viera, Urbinati, Lazzarotti, 2025; García-Quevedo, Llopis, Martínez-Ros, 2020). The above challenges indicate the need for systemic changes outside of organizations in order to create a supportive environment for CE, including, but not limited to, innovative financing models, grants and support for enterprises, research and training.

Among ways of overcoming barriers in the implementation of CE, researchers recommend expanding organizational boundaries, cooperating with external entities and accelerating the commercialization of innovation through shared knowledge and complementary resources (Jesus, Jugend, 2021). These recommendations are expressed in the Open Innovation paradigm, which refers to innovative processes implemented in the enterprise and leading to the implementation of innovation.

3. Open Innovation

According to the Oslo Manual 2018, a business innovation is a new or improved product (product or service) or business process (or combination thereof) that differs significantly from previous products or business processes and that has been placed on the market or brought into use by an enterprise (OECD/Eurostat, 2018).

In contrast to so-called closed innovation, in this mode the boundaries of the organization become more flexible, thus enabling the combination of external sources of knowledge with internal ones in a cooperation ecosystem (Gao et al., 2020). Open innovation was defined by the creator of the concept as the use of purposive inflows and outflows of knowledge to accelerate internal innovation, and expand the markets for external use of innovation (Chesbrough, 2006), and then as a distributed innovation process based on purposefully managed knowledge flows across organizational boundaries, using pecuniary and non-pecuniary mechanisms in line with the organization's business model (Chesbrough, Bogers, 2014).

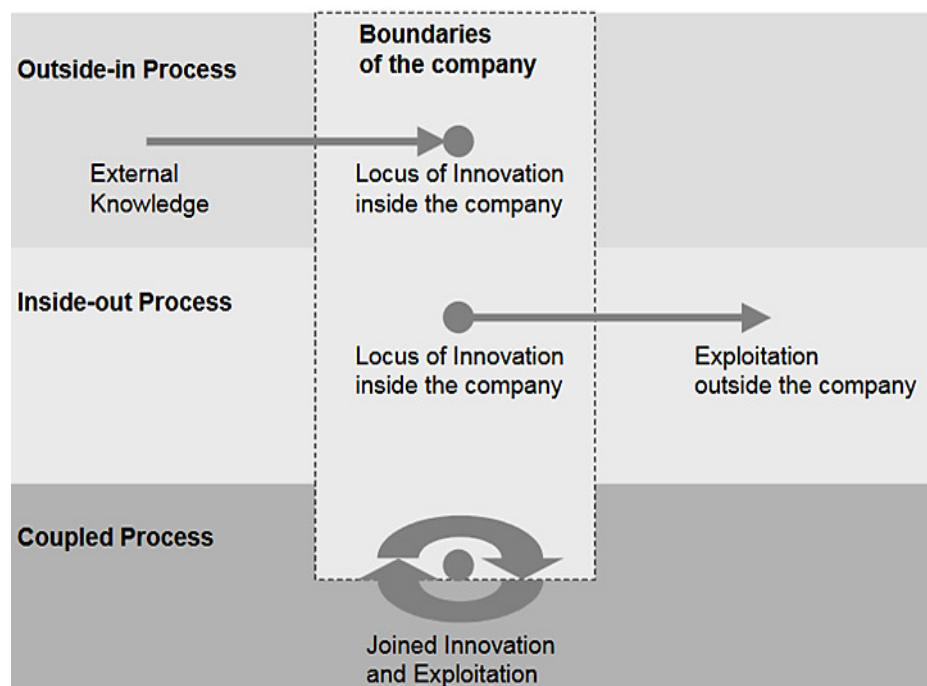


Figure 2. The Open Innovation framework according to O. Gassmann and E. Enkel.

Source: own compilation based on Gassmann, Enkel (2004, p. 6).

The open innovation model describes the directions of knowledge flow across the boundaries of the enterprise, taking into account three basic open innovation processes: centripetal process (outside-in process), centrifugal process (inside-out process) and coupled process (Figure 2). The enterprise unlocks its access boundaries and opens itself to the use of external ideas and solutions (outside-in, or centripetal stream). The inside-out or centrifugal process (stream) leads outside from inside the enterprise, if it decides to make its solutions

available to other organizations, thus unlocking access to its own resources. The coupled process is based on the enterprise's cooperation – both internal and inter-organizational, combining centripetal and centrifugal processes (Bigliardi, Galati, 2016) on the path to co-creating value. Cooperation with external and internal actors, supporting the transfer of knowledge, information, resources and technology, is aimed at the joint creation of innovative solutions and their commercialization. According to researchers, companies seem to be mainly interested in exploiting open innovation in order to reduce the costs of product development or to identify new market opportunities (Strazullo et al., 2025).

Other researchers point to the challenges: factors limiting cooperation between enterprises and institutional partners. These include, among others, the costs of technology transfer, institutional partners' concerns resulting from the lack of experience in the area of technology transfer, rigid procedures (Tartari, Salter, D'Este, 2012) or the management of intellectual property rights. Openness can result in resources being made available for others to exploit, with intellectual property being difficult to protect and benefits from innovation difficult to appropriate (Dahlander, Gann, 2010). According to researchers, “porous firm boundaries result in less proprietary control and increased coordination costs, requiring a joint analysis of open innovation and intellectual property” (Bican et al., 2017, p. 1386). Due to the asymmetry of partners, selecting the right partner for cooperation requires finding the desired matches between the partners' resources, goals and strategies (Arsanti et al., 2022).

OI has the ability to drive the transition to CE, reducing technological barriers to its adoption, such as the lack of knowledge, availability of technical solutions and modifications required for product designs and manufacturing processes. The opening of the company's boundaries, proposed by the IO, may enable the flow of knowledge conducive to the development of CE. The use of the concept of OI in enterprise management should therefore be conducive to reducing barriers in the process of transformation towards a circular economy. For enterprises, the transition to a circular economy is essentially innovation-driven, with a particular focus on product innovation (Chirumalla et al., 2024).

4. Methods

In recent years, the research effort has been directed at the relationship between Open Innovation and Circular Economy in business practice. Research publications devoted to this issue started appearing and the number of publications has significantly increased since 2016, which confirmed growing interest in the topic (Jesus, Jugend, 2021).

The purpose of the study was to determine the possibilities of supporting the circular economy through the implementation of the Open Innovation concept in the enterprise. A thesis was formulated which assumes that the adoption of the Open Innovation paradigm is conducive to the implementation of the principles of the circular economy in the enterprise.

The study was aimed at confirming the thesis. The considerations were based on literature studies and a review of the results of selected secondary research. The basic research method chosen for the purposes of the study is desk research - analysis of existing data. The strengths of this research method are: easy availability of data, cost effectiveness, lack of influence of the researcher on the subject of the study. The weakness is often the inability to verify the reliability of data (Bednarowska, 2015).

For the purposes of the study, an electronic search was conducted using the Google Scholar database, focusing on scientific articles published between 2021 and 2025. The search strategy employed the keywords "Open Innovation" in combination with "Circular Economy" to identify relevant publications.

5. Open Innovation and Circular Economy: Results of a desk research study

The chapter presents interesting results of existing research, presented in scientific publications selected by the author.

Research by G.K.M. Jesus and D. Jugend (2021)

The research by G.K.M. Jesus and D. Jugend aimed to investigate how OI can contribute to the adoption of CE (2021). The researchers conducted a systematic literature review and qualitative analysis of selected articles. A total of 433 items from the Scopus database and 284 items from the Web of Science database were used. Only articles published in journals, in the English language, were considered. Articles from scientific meetings and book chapters were excluded. As a result, the research sample included 24 scientific articles published in the years 2016-2021.

The researchers found that acquisition of knowledge and technologies resulting from the co-creation approach, combined with stakeholder cooperation, can reduce barriers and facilitate the transition to CE (Jesus, Jugend, 2021). The result of the study confirmed the possibility of correlation between OI and CE, and in particular it was found that (Jesus, Jugend, 2021):

- **stakeholder collaboration** can be used to align stakeholders' goals in a joint effort to address environmental issues at three CE levels,
- an approach that promotes **co-creation** can be adopted as a strategy to encourage consumers to participate in the development of environmentally sustainable products, which can foster the transition to CE.

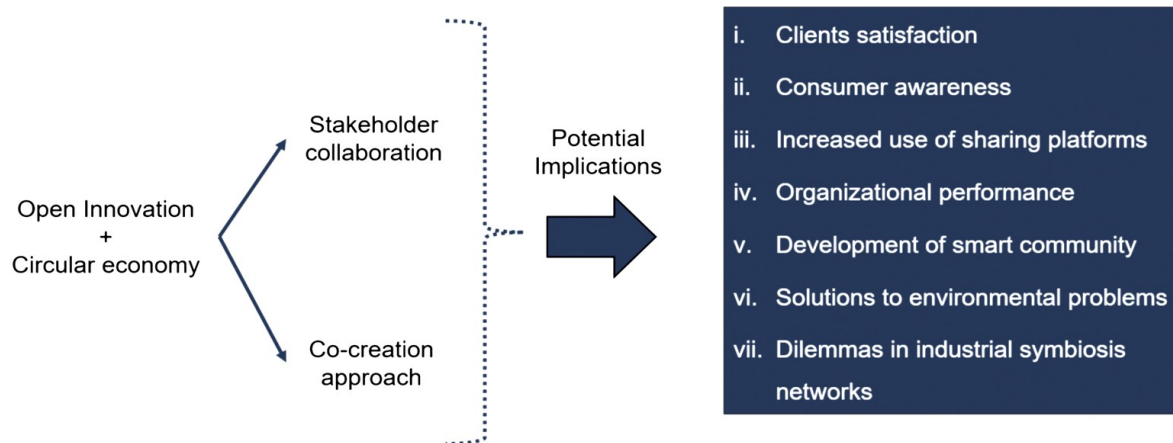


Figure 3. Potential implications for the open innovation-driven CE.

Source: Jesus, Jugend (2021, p. 78).

The set of implications, created by the authors of the discussed existing study on the basis of analyses, is presented in Figure 3 and Table 3.

Table 3.

Potential implications for the open innovation-driven CE

Client satisfaction:	The co-creation approach tends to facilitate the development of solutions for CE as it has the potential to accelerate the development cycle of product designs and business processes while also improving user satisfaction.
Consumer awareness of CE:	The approach based on co-creation and participatory design facilitates interaction and communication between the enterprise and consumers, raising awareness of the importance of sustainable consumption. Enterprises' interaction with consumers can also enable joint development of scenarios for the future and planning of the life cycle of an environmentally sustainable product.
Increased use of sharing platforms:	The co-creation process at the design stage can stimulate the development of online platforms, improve relations with stakeholders. Platforms can also be useful for gathering information about customer needs in CE projects.
Organizational performance improvement:	The co-creation approach, when applied to CE, has the potential to improve the operational efficiency of enterprises, and can lead to increased production and improved financial performance.
Development of smart community:	Co-creation used in a smart community generally means that members of the community participate more actively in decision-making, which results in knowledge exchange between scientific communities, citizens, companies and local administrations.
Solutions to environmental problems:	A co-creation approach can strengthen integrated collaboration between enterprises and communities in order to address local issues. Collaboration between different stakeholders (such as scientists, public authorities, companies, community leaders and citizens) can result in solutions to waste-related problems.
Dilemmas in industrial symbiosis networks:	Greater coordination and sharing of information between network actors can streamline activities such as identification of the value of residues and waste materials and conversion of one company's waste into another company's raw material.

Source: own compilation based on Jesus, Jugend (2021, pp. 78-79).

The results of the discussed existing study, based on an analysis of selected publications from the years 2016-2021, allow for the confirmation of the previously formulated thesis. Activities based on the Open Innovation paradigm can support the development of the Circular Economy. Researchers emphasize the importance of stakeholder cooperation and co-creation, which points to the dominant role of coupled and centripetal (outside-in) processes proposed in the Open Innovation model. Appropriate orientation of these processes may contribute to the implementation of the circular economy concept in the enterprise.

Other studies

The relationships between OI and CE continue to constitute an interesting field of study. Latest research explores and emphasizes the importance of cooperation with stakeholders and co-creation, as elements connecting OI and CE.

For example, contemporary researchers dealing with this topic - in relation to the construction industry - argue that the transition to a circular economy requires establishing cooperation between various entities involved in order to gain access to external competences and to engage in a new way in the entire value chain. OI enables access to these external competences and fosters collaboration throughout the whole value chain (Sgambaro, Chiaroni, Urbinati, 2025).

Other researchers, pursuing research objectives on the basis of case studies and interviews - despite the limitations of this type of study - have presented key insights into barriers to CE and practices within OI (Dorrego-Viera, Urbinati, Lazzarotti, 2025):

- technical barriers, such as skills shortages, knowledge gaps and material quality concerns, have been identified as the most important factors hindering the development of circular economy products,
- OI practices such as publicly funded research and development consortia, consumer **co-creation**, and university collaboration, have been shown to be particularly effective in addressing these barriers.

An interesting result of the above-mentioned research is also the disclosure of significant regional disparities in the ways in which enterprises utilize OI practices to overcome barriers to CE when developing their products: in highly industrialized regions, enterprises focus on advanced technologies and stakeholder engagement, meanwhile in less developed regions they face challenges through bottom-up cooperation and capacity-building efforts (Dorrego-Viera, Urbinati, Lazzarotti, 2025).

According to the researchers, disparities in the ways in which companies utilize OI practices to overcome CE barriers do not depend only on these regional factors. The degree of overlap of the two concepts OI and CI differs according to the type of industry, the size of the organization (start-ups, SMEs, multinational corporations) as well as the degree of openness of each stakeholder (Runiewicz-Wardyn, 2023).

It is worth recalling the results of the study carried out by M. Portuguese-Castro, based on the systematic literature review (SLR) method, and covering 53 scientific articles from the Scopus and Web of Science databases. The objective of the study was to examine the potential of open innovation for **co-creation** in entrepreneurship. The results of this study revealed, among others, that co-creation and open innovation activities enable entrepreneurs to expand their knowledge base through cooperation with various stakeholders (Portuguese-Castro, 2023). Despite the recognition of the importance of this cooperation, the researcher points to existing challenges such as the scarcity of resources and cooperation skills.

By synthesizing the findings of several empirical and literature-based studies, it can be concluded that Open Innovation (OI) — particularly through external and coupled innovation models — can significantly mitigate the technical, economic, and contextual barriers to the transition towards a circular economy. The considerations lead to the confirmation of the thesis that the adoption of the Open Innovation paradigm promotes the development of a circular economy.

6. Discussion

The considerations presented in the study regarding the concepts of Open Innovation and Circular Economy point to the complexity and multidimensionality of each of them. On the other hand, they also show the possibilities for combining seemingly divergent paradigms. The research problem taken up in the study, narrowed down to the level of enterprises, focused on the question of whether the adoption of the Open Innovation concept has an impact on the transformation towards a circular economy.

The results of the existing research used provide valuable insights into the importance of Open Innovation for the development of the circular economy. Actions based on the Open Innovation (OI) paradigm can support the development of the Circular Economy (CE), which is an important indication in the era of ecological transformation and the implementation of sustainable development goals.

The researchers emphasize the importance of stakeholder cooperation and co-creation, which indicates the dominant role of coupled and centripetal processes proposed in the Open Innovation model. Appropriate direction of these processes can contribute to the implementation of the circular economy concept in the enterprise. In light of the research results, special emphasis is placed on cooperation with stakeholders and co-creation.

The co-creation approach, when applied to CE, has the potential to improve the operational efficiency of enterprises, can lead to increased production and improved financial results. The emphasized actions primarily fulfill centripetal and coupled processes within the open innovation model. Making a joint effort for innovative solutions promotes the development of

the circular economy, leading to increased resource efficiency. Attention was drawn to regional disparities.

The considerations presented in the study do not exhaust the problem, but can serve as an inspiration for further research efforts aimed at identifying strategic factors positively impacting the benefits of cooperation and co-creation, and thereby promoting the development of the circular economy in pursuit of sustainable development.

Further scientific research on the effects of the practical application of the open innovation paradigm for the development of the circular economy should relate not only to enterprises, but also to cities, regions or the national economy.

7. Conclusions

From a practical point of view, these results may provide valuable insights for managers in enterprises interested in the development of the circular economy in the context of the implementation of sustainable development goals. The study promotes managers' focus on the Open Innovation paradigm for the purpose of accelerating the transition to the circular economy. This especially relates to cooperation with stakeholders and co-creation, which translate to centripetal (outside-in) and coupled processes within the OI model.

Innovative activity based on the Open Innovation formula should not be undertaken in an incidental manner. A strategic approach is recommended. It should be manifested in an innovative strategy leading to the exchange of knowledge and experience and development of lasting partnerships between enterprises. Opening up to cooperation with external partners also requires a strategic approach to the protection of intellectual property rights, determining beneficial relations between stakeholders, and aimed at the development of a circular economy.

Effective use of open innovation approaches requires a supportive and collaborative company culture (Aytekin, Korucuk, 2025). One associated challenge for managers is the transformation of the organizational culture towards openness, rejecting reluctance to cooperate and co-create. Leadership inspiring the effective use of key competences of employees and joint search for new solutions is in line with the strategic goals of an enterprise striving for the development of circular economy as an area important from the point of view of sustainable development.

In the era of development of Industry 4.0, it is necessary to explore the potential for utilization of information and communication technologies – i.e. a wider use of digital platforms and artificial intelligence – in facilitating cooperation, diagnosing existing patterns, forecasting trends and designing innovative solutions in the field of CE.

8. Summary

This article examines the complementarity between the concepts of Open Innovation (OI) and Circular Economy (CE), focusing on how the adoption of OI strategies in companies can facilitate the implementation of CE principles. The author bases the analysis on literature research and a review of secondary research, with a special focus on stakeholder collaboration and co-creation processes. Based on a synthesis of the results of several empirical and literature-based studies, it shows that OI - especially through processes based on external and coupled innovation - can mitigate technical, economic and contextual barriers to the transition to a circular economy. The article concludes with practical recommendations for managers and a call for the conscious use of OI tools in the process of sustainable transformation.

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ARTIFICIAL INTELLIGENCE AND HUMANS IN THE MANUFACTURING SECTOR: WORKING IN SYMBIOSIS OR SEPARATELY?

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Purpose: This paper aims to provide a theoretical analysis of the relationship between humans and artificial intelligence (AI) in the manufacturing sector, exploring whether they operate as symbiotic collaborators within integrated systems or as independent entities with distinct roles and impacts on organizational structures.

Design/methodology/approach: The study employs conceptual analysis grounded in a semi-systematic literature review covering research from 2015 to 2025. The approach identifies, categorizes, and interprets key models of human-AI interaction, system integration strategies, and organizational implications, synthesizing insights across interdisciplinary sources.

Findings: Findings reveal a dominant trend toward cooperative and supportive models of human-AI interaction, where AI augments rather than replaces human roles. Five core design principles are identified: human-centered design, explainability and transparency, adaptive task allocation, strategic role definition, and hybrid intelligence. While benefits such as increased trust, ergonomic improvements, and flexibility are evident, significant challenges persist, particularly regarding system complexity, role ambiguity, and the risk of human skill dequalification.

Research limitations/implications: The study is limited by its reliance on secondary data and the absence of empirical validation in real-world settings. Furthermore, the semi-systematic review may have excluded relevant or unpublished studies. Future research should focus on empirically testing the proposed frameworks and exploring dynamic human-AI co-learning processes in industrial contexts.

Originality/value: This article contributes original value by introducing an integrated conceptual framework for analysing human-AI interaction in manufacturing. It shifts the discourse from purely technical assessments toward socio-technical and relational perspectives. The paper offers actionable guidance for system designers, managers, and policymakers, emphasizing the need for context-aware, human-centered integration of AI technologies.

Keywords: humans, AI, manufacturing sector, collaboration.

Category of the paper: conceptual paper.

1. Introduction

The rapid development of artificial intelligence (AI) technologies within the framework of Industry 4.0 has profoundly reshaped the manufacturing landscape. What was once a domain dominated by rigid automation is now evolving toward flexible, adaptive systems where AI and human agents increasingly co-exist. These changes are not merely technological but also organizational and social, prompting new questions about the nature of human-machine interaction in modern production settings (Jarrahi, 2018). At the heart of this transformation lies the relationship between humans and AI. While AI offers unparalleled capabilities in processing data, optimizing operations, and enabling real-time decision-making, the human contribution remains critical—particularly in areas requiring contextual understanding, ethical judgment, or creativity. As such, the interaction between AI and humans in manufacturing is no longer a question of replacement, but rather of how best to structure their coexistence. This interaction is often framed as a continuum between two models: symbiosis, where human and AI systems collaborate and complement one another; and independence, where AI technologies operate autonomously or displace human roles (Mahmud et al., 2022; Esfahani et al., 2022).

The dominant narrative in contemporary research increasingly supports symbiotic models, emphasizing shared agency, human-in-the-loop systems, and adaptive cooperation in tasks ranging from decision-making to generative design and additive manufacturing (Mahmud et al., 2022; Bendoly et al., 2023; Esfahani et al., 2022). Nevertheless, critical limitations persist. For example, meta-analyses suggest that human-AI combinations do not always outperform either agent working alone, particularly in decision-making domains where coordination challenges can impede performance (Vaccaro et al., 2024). Furthermore, the over-reliance on AI systems may lead to cognitive skill degradation among human operators, raising concerns about explainability, trust, and long-term system sustainability (Becks, Weis, 2022).

Despite growing interest, there remains a notable research gap in terms of theoretical integration and interaction modelling. Current literature lacks cohesive frameworks and unified vocabulary for understanding the complex, dynamic relationships between human and AI actors in real-world manufacturing environments. In particular, there is limited theoretical and practical attention to the design of interaction models, mutual adaptation, and cooperative behaviour over time (Garcia et al., 2021; Rezwana, Maher, 2022). Most contributions are fragmented across disciplinary boundaries, often emphasizing technical capabilities of AI rather than relational and systemic dimensions of collaboration.

This article aims to address this gap by presenting a theoretical analysis of human-AI interaction in the manufacturing sector, situated within the broader context of organizational, technological, and societal transformations. Drawing on a semi-systematic literature review, it develops interpretive frameworks to assess the coexistence of humans and AI as either

elements in symbiosis or independent entities. The paper explores how these interaction models manifest in practice, the tensions they produce, and the implications they carry for design, work organization, and long-term human-AI integration.

Filling this gap is important for both theoretical and practical reasons. A deeper understanding of cooperative versus independent system dynamics can inform the design of more resilient, adaptive, and ethically sound production systems. It can also guide policymakers, engineers, and organizational leaders in making informed decisions about how to balance human and AI contributions without sacrificing agency, trust, or long-term learning.

The structure of the article is as follows. First, it provides a theoretical background on the evolving dynamics of human-AI interaction in the manufacturing sector, including key collaboration models, enabling technologies, and organizational factors. Next, the research methodology is described, based on a conceptual analysis conducted through a semi-systematic literature review. The main findings are then presented across four analytical dimensions: collaboration patterns, system integration approaches, impact on work organization, and design implications. The article concludes with a synthesis of the benefits and challenges observed, followed by a discussion of theoretical and practical contributions and directions for future research.

2. Theoretical background

Human-AI interaction in the manufacturing sector is undergoing a significant transformation, evolving from traditional automation toward integrated, human-centric systems. This shift reflects the core tenets of Industry 4.0 and the emerging Industry 5.0 paradigm, where artificial intelligence is not viewed as a replacement for human labour but as a synergistic partner that enhances human capabilities, supports decision-making, and enables more flexible, efficient, and adaptive production. The integration of collaborative technologies such as cobots, digital twins, and advanced analytics plays a central role in optimizing workflows, improving product quality, and minimizing errors. AI augments rather than replaces human input, fostering more personalized and innovation-driven environments (Rakholia et al., 2024; Othman, Yang, 2023; Asaad et al., 2024; Anang et al., 2024).

An essential aspect of this evolution is the emphasis on human-centric design. Modern manufacturing systems increasingly prioritize trust, transparency, and participatory processes through the deployment of explainable AI and adaptive interfaces that respond to human input and oversight. These approaches aim to strengthen operator confidence and ensure safe, understandable, and accountable AI behaviour (Li et al., 2025; Rani et al., 2024; Anang et al., 2024). A key theoretical foundation underpinning human-AI collaboration is cognitive synergy, where AI excels in structured, data-intensive operations while humans contribute contextual

awareness and problem-solving flexibility. The integration of these complementary strengths, often facilitated by reinforcement learning and real-time interaction mechanisms, enables the development of resilient, semi-autonomous systems that can operate effectively in complex manufacturing settings (Mukherjee et al., 2024; Fan et al., 2025).

In the literature, three primary models of human-AI collaboration in manufacturing have been identified: cooperative, supportive, and independent. In cooperative models, humans and AI systems jointly perform shared tasks, requiring real-time coordination and mutual adaptation. These are exemplified by collaborative robotics and human-in-the-loop systems, where both agents actively contribute to task completion (Trakadas et al., 2020; Murali et al., 2020; Hartikainen et al., 2024). Supportive models assign the AI a more auxiliary role, where it provides information, physical assistance, or recommendations, while decision-making remains primarily in human hands. Applications include AI-supported decision-making systems and ergonomic aids (Roveda et al., 2020; Hartikainen et al., 2024). In independent models, AI and human agents work on parallel tasks with limited interaction, integrating outputs at a systemic level. Although less integrated, this model remains relevant in highly automated environments such as inspection and logistics (Matheson et al., 2019).

Several enabling technologies support these collaborative frameworks. Human-in-the-loop systems ensure that while AI may generate insights or propose actions, humans maintain control over key decisions (Trakadas et al., 2020; Murali et al., 2020). Human-on-the-loop models, on the other hand, allow AI to operate with a higher degree of autonomy, with humans positioned as supervisory agents who can intervene when necessary. Human-out-of-the-loop systems function independently of human input, suitable only for narrowly defined and highly structured scenarios. A particularly promising development is adaptive symbiosis, in which humans and AI systems co-learn over time. This mutual adaptation enhances shared understanding and system responsiveness, as seen in machine tool operation environments where AI systems adjust to operator preferences.

Technological infrastructure such as AI-IoT integration facilitates predictive maintenance and real-time analytics, contributing to more responsive and efficient production processes (Rani et al., 2024; Hartikainen et al., 2024). Formal tools like knowledge graphs and process models support structured, transparent, and accountable interactions between humans and AI by encoding relationships and improving data traceability (Heinzl et al., 2024). Moreover, advanced control methods such as model-based reinforcement learning and variable impedance control, enhance safety and responsiveness during physical collaboration between humans and robotic agents (Roveda et al., 2020).

Effective human-AI collaboration also requires careful attention to design and organizational context. Ergonomic and human-centered workspace design ensures both physical safety and psychological well-being, while task planning mechanisms must be flexible enough to adapt to human behaviour and contextual changes (Simões et al., 2022; Roveda et al., 2020). Finally, organizational factors such as company size, resource availability,

and workforce skill levels play a critical role in shaping the success of implementation strategies. Tailored approaches are necessary to align technological integration with specific operational realities (Sun, Song, 2024). In sum, the integration of AI in manufacturing must be approached not only as a technical challenge but also as a socio-technical endeavor grounded in collaborative design, adaptive systems, and organizational readiness.

3. Research methodology

The paper adopts a method of conceptual analysis (Rocco and Plakhotnik, 2009) based on a semi-systematic literature review (Snyder, 2019). The use of conceptual analysis is justified by the need to systematically identify, categorize, and clarify key concepts and their interrelations within the studied phenomenon. As noted by Miles and Huberman (1994), a conceptual framework serves not only to organize relevant ideas but also to reveal “where the overlaps, contradictions, refinements, or qualifications are” (Miles, Huberman, 1994, p. 18). This method enables the development of a structured analytical lens through which complex qualitative data can be interpreted. By integrating both theoretical insights and empirical findings, conceptual analysis supports the construction of a coherent and transparent framework that enhances the explanatory power of the study.

As a conceptual paper, this study is based on the synthesis of representative literature from a specific domain, integrated to provide a better understanding and conceptualization of the research phenomenon (Rocco, Plakhotnik, 2009). The rapid technological advancements and the ongoing transformation of human–AI collaboration in the manufacturing sector justify the use of conceptual analysis via a semi-systematic literature review in this study. Although research in this field has developed over several decades, supported by a balanced body of theoretical and empirical work, the accelerating pace of innovation calls for a deeper understanding of the evolving conceptual landscape. As noted in recent literature, there remains a pressing need to bridge theoretical frameworks with empirical insights to capture the full complexity and implications of AI integration in human work environments.

Conceptual analysis enables a systematic exploration and clarification of key ideas, roles, and relationships, providing a foundation for future empirical investigations and ensuring analytical coherence in a rapidly changing domain. According to Hulland (2020, p. 27), “conceptual review papers can theoretically enrich the field by reviewing extant knowledge, noting tensions and inconsistencies, identifying important gaps as well as key insights, and proposing agendas for future research”. This approach is crucial in fields where theoretical clarity is needed to guide empirical inquiry. To conduct the semi-systematic literature review and conceptual analysis, the author followed the phases suggested by Snyder (2019). First, the review was designed, including the formulation of a guiding research question.

Second, relevant studies were identified through a systematic search. Third, the selected papers were conceptually analysed, and finally, the review was written. In the first phase, the author formulated the research question, identified key data sources, and developed relevant search phrases. The conceptual analysis was guided by the following research question:

RQ1. *Do AI and humans form collaborative, mutually supportive links within a single system, or are they evolving as independent components, each with its own operational logic and impact on the organization?*

The Scopus and Google Scholar databases were used to search for publications containing the phrases: “human-AI collaboration” OR “socio-technical systems” OR “task allocation” OR “organizational impact of AI”. This combination of search terms and databases enabled the author to identify studies analysing the interaction between AI and humans in the manufacturing sector. The search targeted papers in the field of Business, Management, and Accounting, including all publications from 2015 up to May 1, 2025, and was limited to articles written in English or German. The time frame from 2015 to 2025 was selected because research on artificial intelligence in manufacturing has significantly intensified since 2015, driven by the rise of Industry 4.0. Including publications up to 2025 ensures the analysis captures the most recent developments and reflects the ongoing shift toward human-centric collaboration models associated with Industry 5.0. For the analysis, the author applied inclusion and exclusion criteria (Paul, Criado, 2020). The inclusion criteria comprised studies that focused on the interaction between AI and humans within manufacturing environments. Studies that primarily examined technical aspects of AI or addressed general automation rather than intelligent systems were excluded. In analysing the selected papers, the initial focus was on how the interaction between artificial intelligence systems and human actors is conceptualized and operationalized in manufacturing contexts. Special attention was given to the nature of human-AI collaboration, the distribution of roles and responsibilities, and the assumptions underlying system design. This involved mapping various cooperation models, levels of autonomy, and integration strategies described in the literature.

By systematically applying the inclusion criteria, emphasizing empirical grounding, relevance to the manufacturing context, and a clear focus on intelligent systems, the analysis aimed to develop a coherent conceptual foundation for understanding human-AI dynamics in industrial environments. In addressing RQ1, the analysis highlighted how reviewed studies conceptualize and operationalize the human-AI relationship in manufacturing. As a result, three key elements were identified: (1) insights into cooperative versus independent system dynamics, (2) recognition of main challenges in human-AI collaboration, and (3) directions for future research. These findings underscore the predominance of integrative collaboration models, recurring barriers such as system complexity and skill mismatches, and the importance of human-centered, transparent design approaches. Together, these elements provide a conceptual basis for further investigation into human-AI interaction in manufacturing.

4. Results and findings

In the following section, a synthesis of findings is presented across four key analytical dimensions: summary of study characteristics, outlining the methodological and contextual features of the reviewed research, thematic analysis of human-artificial intelligence collaboration patterns, capturing dominant models of interaction and role distribution between humans and AI, system integration approaches, focusing on technical, organizational, and operational strategies for embedding AI in manufacturing settings; and impact on work organization, examining how AI influences task structures, skill requirements, and human roles. Each dimension contributes to a more comprehensive understanding of the evolving relationship between humans and AI in the manufacturing sector.

Summary of study characteristics

The reviewed studies employed a range of research approaches (see Table 1). Empirical methods were the most commonly used, featured in 13 studies. Additionally, 9 studies adopted theoretical or conceptual frameworks, while 7 relied on case study methodologies. Mixed methods were used in 3 studies, and 2 studies were literature reviews. It is noteworthy that several studies employed more than one methodological approach.

In terms of industry context, 21 studies were conducted within manufacturing or assembly environments, indicating a strong sectoral focus. Four studies explicitly addressed contexts related to Industry 4.0 or Industry 5.0, while one study included multiple sectors, reflecting a broader applicability. Some studies spanned more than one industrial domain.

The nature of the human–artificial intelligence (AI) relationship varied across studies. Twelve studies characterized this relationship as “cooperative,” while 10 described it as “cooperative/supportive.” The term “supportive” was used in 2 studies, with an additional 1 study using the term “supportive/cooperative.” One study introduced the concept of “hybrid intelligence” to describe the interaction between humans and AI.

Several key themes emerged from the reviewed literature. Trust and transparency were highlighted in 5 studies. Other recurring themes included human-centered design, usability, or acceptance (2 studies); ergonomics or operator well-being (2 studies); mutual learning (2 studies); human factors (2 studies); adaptability (2 studies); and fatigue monitoring (2 studies). Additional themes, each addressed in a single study, included: teamwork, augmentation, ethics, productivity, socio-technical focus, strategic planning, training needs, design complexity, peer-to-peer interaction, human-friendly automation, complementary skills, co-creation, risk of dequalification, and joint decision-making.

Table 1.
Characteristics of included studies

Study	Study Focus	Research Approach	Industry Context	Key Findings
Emmanouilidis et al., 2021	Human-AI integration in production; vision-based inspection	Case study, Theoretical/conceptual	Manufacturing (vision-based inspection, Industry 5.0, digital twins, Explainable artificial intelligence)	Cooperative human-AI model; trust and transparency critical; humans enhance AI capabilities; need for work design considerations
Pacaux-Lemoine et al., 2017	Human-machine cooperation in intelligent manufacturing	Mixed methods (theoretical/Conceptual + empirical)	Intelligent Manufacturing Systems (adaptive self-organization, Industry 4.0)	Cooperative/supportive model; human-centred design; need for human integration in autonomous systems
Pacaux-Lemoine et al., 2016	Human-machine cooperation principles	Theoretical/conceptual	Intelligent Manufacturing Systems	Cooperative/supportive; mutual understanding and communication; human-machine cooperation principles improve performance
Bechinie et al., 2024	Human-centered intelligent assistance; Operator 5.0	Theoretical/conceptual, Literature review	Manufacturing (Digital Twins, extended reality, artificial intelligence)	Cooperative/supportive; usability, acceptance, understandability; challenges in human-centered design
Dimitropoulos et al., 2021	Human-robot collaborative assembly	Case study, Empirical	Elevator manufacturing (digital twins, vision machine learning)	Cooperative/supportive; robot adapts to human needs; improved ergonomics and satisfaction
Habib et al., 2021	Human-machine cooperation in Manufacturing 4.0	Empirical	Manufacturing (digital twins, mobile robots)	Cooperative; teamwork reduces workload; individual factors affect cooperation
Pacaux-Lemoine et al., 2022	Human-system cooperation with cognitive work analysis	Empirical	Industry 4.0 (intelligent systems, digital twin)	Supportive; cognitive work analysis aids situational awareness; complexity challenges; need for better cooperation tools
Oh, 2023	Artificial intelligence impact on workforce competencies	Mixed methods	Advanced Manufacturing (natural Language processing)	Cooperative; artificial intelligence augments but does not replace humans; role clarity needed
Rožanec et al., 2023	Artificial intelligence in defect detection; operator fatigue	Empirical	Manufacturing (quality inspection, machine learning)	Cooperative/supportive; artificial intelligence aids defect detection; fatigue monitoring enhances well-being
Peruzzini et al., 2023	Human-automation symbiosis in Industry 5.0	Theoretical/conceptual	Diverse sectors (Augmented Digital Twin)	Cooperative/supportive; mutual learning; human factors central
Sesana and Tavola, 2021	Artificial intelligence/augmented reality for resilient manufacturing	Empirical	Manufacturing/assembly (Internet of Things, augmented reality, neural networks)	Cooperative; augmented reality supports operators; trust and transparency; real-time data sharing
Albu-Schäffer et al., 2023	Socio-technical assistive systems; learning	Theoretical/conceptual, Empirical	Industrial production (knowledgebased, ontologies)	Cooperative; mixed-skill task allocation; learning promotion; risk of dequalification
Süsse et al., 2023	Human-artificial intelligence interaction in remanufacturing	Case study	Automotive/remanufacturing (artificial intelligence agent)	Supportive/Cooperative; joint decision-making; behavioural patterns (cognitive, emotional, social)
Oliff et al., 2020	Human-robot interaction; adaptability	Theoretical/conceptual, Empirical, Case study	Assembly/manufacturing, (machine learning, cyber-physical systems, virtual reality/augmented reality)	Cooperative/supportive; adaptability to human variation; need for further research

Cont. table 1.

Dvorak et al., 2022	Human role in artificial intelligence-based production	Theoretical/conceptual	Electric motor Production (artificial Intelligence assistance)	Supportive; artificial intelligence assists complex tasks; focus on socio-technical system
Saßmannshausen, Heupel, 2020	Trust in artificial intelligence in production management	Empirical	Industrie 4.0 (Big Data, Predictive Analytics, Robotics)	Cooperative/supportive; trust is crucial; unpredictability is a challenge
Rožanec et al., "Predicting Operators Fatigue"	Artificial Intelligence-driven defect detection; fatigue	Empirical	Manufacturing (quality inspection, machine learning)	Cooperative/supportive; artificial intelligence aids workflow; fatigue monitoring
Wahlström et al., 2024	Artificial intelligence and transformation of industrial work	Case study, Theoretical/conceptual	Glass tempering (machine vision, automation)	Cooperative; hybrid intelligence; "double black box" challenge
Hartikainen et al., 2024	Human artificial intelligence collaboration in smart manufacturing	Literature review	Manufacturing (artificial Intelligence enabled agents)	Cooperative; trust, transparency, ethics; operator well-being
Waschull, Emmanouilidis, 2022	Human-centric co-creation for artificial intelligence systems	Empirical	Manufacturing (artificial Intelligence enabled systems)	Cooperative; trust; human factors in design; co-creation workshops
Schierhorst et al., 2024	Hybrid intelligence in production	Case study	Industry 4.0 (artificial Intelligence applications, coating/machining)	Cooperative; human-friendly automation; productivity focus
Yamamoto et al., 2024	Human-centered artificial intelligence system design	Case study	Manufacturing (machine learning anomaly detection, casting)	Cooperative; design complexity; need for structured approach
Umbrico et al., 2022	Enhanced cognition for human-robot collaboration	Empirical	Human-robot collaboration Manufacturing (artificial intelligence, cyber-physical systems)	Cooperative/supportive; peer-to-peer interaction; adaptability
Żywiółek, 2024	Trust-building in artificial intelligence human partnerships	Empirical	Manufacturing (pattern recognition, classification)	Cooperative; trust, transparency, ethics; training needs
Gabriel et al., 2023	Strategic planning for human-artificial intelligence collaboration	Mixed methods	Manufacturing (no further details found)	Cooperative; complementary skills; need for strategic planning

Source: own elaboration.

Thematic analysis of human–artificial intelligence collaboration patterns

The thematic analysis of the reviewed studies reveals a coherent and evolving pattern of human–artificial intelligence (AI) collaboration within industrial contexts. A prevailing model observed across the literature is that of cooperative or supportive integration, in which AI systems are not designed to function independently but rather to augment, assist, or collaborate with human operators (Emmanouilidis et al., 2021). This paradigm reflects a shift toward human-centered automation, where human agency and oversight are preserved. Such cooperative arrangements are particularly evident in applications like vision-based inspection (Emmanouilidis et al., 2021), collaborative robotic assembly (Dimitropoulos et al., 2021), and remanufacturing processes (Süsse et al., 2023), where AI enhances human capabilities by providing computational precision, real-time assistance, and decision support. In a smaller subset of studies, the concept of hybrid intelligence is introduced, emphasizing the synergistic fusion of human cognitive flexibility and ethical judgment with the data-processing efficiency and consistency of AI systems (Wahlström et al., 2024; Nikolas et al., 2024).

This model proposes a more integrated approach to task execution, wherein both agents contribute unique and complementary strengths.

The distribution of roles and the allocation of tasks between humans and AI agents emerge as critical dimensions of collaborative system design (Dimitropoulos et al., 2021). Numerous studies report the implementation of dynamic task allocation mechanisms, allowing AI systems to adapt to individual human operators based on real-time performance metrics, preferences, or situational demands (Dimitropoulos et al., 2021). These systems often rely on mixed-skill allocation strategies, assigning tasks based on the respective advantages of human and artificial capabilities (Albu-Schäffer et al., 2023). Human involvement is most commonly positioned in supervisory and decision-making roles (Emmanouilidis et al., 2021), where contextual understanding and ethical reasoning are essential, as well as in direct operational tasks requiring manual dexterity and adaptability (Dimitropoulos et al., 2021). Additionally, humans frequently assume responsibility for workflow coordination, overseeing the sequencing and interaction of hybrid teams (Rožanec et al., 2023). This adaptive and complementary role distribution underscores the importance of flexibility and situational responsiveness in the design of collaborative systems.

A central enabling factor in effective human-AI collaboration is the quality of communication interfaces. The studies consistently emphasize the need for transparent, interpretable, and user-centered interaction mechanisms to foster trust, enhance usability, and ensure operational safety (Emmanouilidis et al., 2021). Explainable AI is identified as a key approach, allowing AI systems to convey their reasoning processes in an accessible manner, thereby supporting human understanding and accountability (Emmanouilidis et al., 2021). Augmented reality interfaces are also reported as valuable tools, providing contextualized visual information that supports task performance and situational awareness (Bechinie et al., 2024). Natural language processing capabilities further facilitate intuitive and low-friction communication, enabling users to interact with AI systems using everyday language (Oh, 2023). In several cases, participatory design practices, such as co-creation workshops, are employed to integrate end-user perspectives and human factors into system development from the outset (Bechinie et al., 2024; Waschull, Emmanouilidis, 2022). These methods contribute to the alignment of technological capabilities with user needs, promoting acceptance, usability, and long-term sustainability of AI integration.

In summary, the reviewed studies converge on a model of human-AI collaboration that is grounded in cooperation, mutual adaptability, and transparent interaction. Rather than displacing human labour, AI systems are increasingly conceptualized as collaborative partners that enhance human potential while maintaining essential human oversight and judgment. This integrative perspective reflects a broader socio-technical orientation in the design of intelligent systems and offers a foundation for future research and practice in human-centered AI deployment.

System integration approaches

The reviewed studies identify three major dimensions of system integration in the context of human–artificial intelligence (AI) collaboration (Emmanouilidis et al., 2021; Albu-Schäffer et al., 2023; Oliff et al., 2020): technical integration frameworks, organizational adaptation strategies, and performance optimization methods. In terms of technical integration, AI systems are incorporated into industrial environments through advanced frameworks such as digital twins, knowledge-based systems, and cyber-physical systems. These architectures facilitate real-time data exchange, continuous process monitoring, and adaptive system control, enabling responsive and context-aware collaboration between human operators and AI agents (Emmanouilidis et al., 2021). Despite their potential, several studies emphasize challenges associated with the complexity of these systems, particularly the need for reliable and timely data sharing across heterogeneous technological infrastructures (Emmanouilidis et al., 2021; Pacaux-Lemoine et al., 2021; Sesana, Tavola, 2021).

At the organizational level, integration efforts are supported by a variety of adaptation strategies aimed at aligning technological capabilities with human and institutional needs (Bechinie et al., 2024). Key approaches include human-centered design methodologies, co-creation workshops, and strategic planning focused on role definition and capability mapping (Bechinie et al., 2024; Waschull, Emmanouilidis, 2022; Hartikainen et al., 2024). These strategies are designed to ensure that the deployment of AI technologies supports both organizational goals and individual user needs. Numerous studies stress the importance of structured training programs and clearly defined role allocations to facilitate smooth integration and promote acceptance among human workers (Hartikainen et al., 2024; Żywiołek, 2024; Gabriel et al., 2023).

From a performance optimization perspective, AI systems contribute to enhanced operational efficiency through real-time process monitoring, ergonomic assessment, and adaptive task allocation based on system or human conditions (Dimitropoulos et al., 2021; Bechinie et al., 2024; Emmanouilidis et al., 2021; Albu-Schäffer et al., 2023). While these applications offer measurable benefits in productivity and safety, several studies also identify critical barriers. These include the inherent complexity of integrated systems (Emmanouilidis et al., 2021; Pacaux-Lemoine et al., 2021), the skill demands placed on human operators (Hartikainen et al., 2024; Żywiołek, 2024), and the so-called "double black box" problem, where both the AI system's decision-making logic and the human operator's cognitive processes are non-transparent (Wahlström et al., 2024; Yamamoto et al., 2024). This opacity presents challenges for accountability, interpretability, and effective human-machine collaboration.

In summary, successful system integration in human-AI collaboration relies not only on sophisticated technical frameworks but also on adaptive organizational strategies and targeted performance optimization efforts. These components must be cohesively aligned to address the sociotechnical challenges of complexity, transparency, and human-system coordination.

Impact on work organization

The integration of artificial intelligence into work environments results in substantial changes to work organization, particularly in the nature of tasks, skill requirements, and operational performance (Emmanouilidis et al., 2021; Dimitropoulos et al., 2021; Pacaux-Lemoine et al., 2021; Oh, 2023).

In terms of task transformation, the implementation of AI systems leads to a marked shift in human roles from manual task execution to higher-level responsibilities such as supervision, decision-making, and workflow coordination (Emmanouilidis et al., 2021; Pacaux-Lemoine et al., 2021; Oh, 2023). As AI systems increasingly handle routine and computational tasks, human operators are more frequently engaged in complex, context-dependent activities that require situational awareness and judgment (Wahlström et al., 2024; Hartikainen et al., 2024; Żywiołek, 2024). Several studies also report trends toward upskilling, indicating a growing need for workers to acquire new competencies in response to evolving job demands (Wahlström et al., 2024; Hartikainen et al., 2024; Żywiołek, 2024).

Skill requirements are a recurring theme throughout the literature (Habib et al., 2021). The emergence of AI-driven work processes is associated with increasing demands for higher-order cognitive abilities, technical skills, and collaborative competencies, particularly in multidisciplinary and human-AI teams (Habib et al., 2021; Oh, 2023; Hartikainen et al., 2024). Additionally, some studies highlight the influence of individual factors, such as previous experience, adaptability, and personal characteristics, on how effectively workers engage with and adapt to AI systems (Wahlström et al., 2024; Hartikainen et al., 2024; Żywiołek, 2024).

With respect to operational efficiency, most studies report improvements in productivity, workplace ergonomics, and user satisfaction when human-AI collaboration is carefully designed and implemented (Dimitropoulos et al., 2021; Habib et al., 2021; Rožanec et al., 2023). These benefits are often linked to the complementary capabilities of humans and AI, as well as to systems that are user-centric and transparent. However, the available evidence is frequently derived from case studies or simulated environments, limiting the generalizability of findings (Dimitropoulos et al., 2021; Süsse et al., 2023; Oliff et al., 2020; Schierhorst et al., 2024). Furthermore, challenges such as lack of trust, limited system transparency, and technical complexity are commonly identified as barriers that may diminish or obstruct the realization of expected benefits (Emmanouilidis et al., 2021; Pacaux-Lemoine et al., 2021; Sesana, Tavola, 2021; Saßmannshausen, Heupel 2020; Wahlström et al., 2024).

In summary, the impact of AI on work organization is multifaceted. While it offers significant opportunities for performance improvement and job enrichment, it also introduces new demands on skills, human-system interaction, and organizational adaptation.

Design Implications

The Table 2 presents the results of a literature-based analysis of key design principles for effective human-AI collaboration. It outlines five foundational principles identified as critical for integrating artificial intelligence into work environments. For each principle, the table

summarizes typical implementation approaches, observed benefits, and associated challenges. The findings highlight that while the adoption of advanced design strategies can enhance trust, operational flexibility, and collaborative efficiency, they are also accompanied by significant organizational, technological, and skill-related challenges that require careful and systematic consideration.

Table 2.
Design implications

Desing Principle	Implementation Approach	Benefits	Challenges
Human-centered design	Co-creation workshops, participatory design, human factors integration	Improved trust, usability, early identification of issues	Lack of structured methods, complexity in integrating human factors
Explainability and transparency	Explainable artificial intelligence, augmented reality interfaces, real-time data sharing	Enhanced trust, operator acceptance, better decision-making	Complexity, "double black box" effect, need for expert networks
Adaptive task allocation	Mixed-skill concepts, knowledge-based systems, ergonomic assessment	Flexibility, learning promotion, operational efficiency	Risk of dequalification, objectification trap, misuse for performance monitoring
Strategic role definition	Capability assessment, strategic planning, training	Clearer roles, improved collaboration, readiness for artificial intelligence integration	Organizational resistance, varying stakeholder priorities, training needs
Hybrid intelligence	Integration of human and artificial intelligence strengths, mutual learning	Productivity, human-friendly automation, resilience	Skill mismatches, need for upskilling, system complexity

Source: own elaboration.

Based on the analysis presented in the Table 2 , the review identifies and synthesizes five core design principles that shape effective human-AI collaboration: human-centered design, explainability and transparency, adaptive task allocation, strategic role definition, and hybrid intelligence. Each principle is linked to specific implementation approaches and has demonstrated distinct benefits and challenges in practice. Observed benefits include enhanced or improved trust (reported across two principles), as well as a range of individual benefits reported once each: increased usability, early issue detection, operator acceptance, better decision-making, flexibility, learning promotion, operational efficiency, clearer role definitions, improved collaboration, readiness for AI integration, productivity, human-friendly automation, and system resilience. These findings reflect a broad spectrum of positive outcomes that stem from aligning design approaches with both technical and human factors. On the challenge side, system complexity and the complexity of integrating human factors were the most commonly cited issues, appearing in relation to three design principles. Additionally, a series of unique but critical challenges such as lack of structured methods, the "double black box" effect, need for expert networks, risks of dequalification, misuse for monitoring, and organizational resistance, highlight the multifaceted nature of obstacles faced in implementing these principles.

5. Conclusions, research limitations and further research directions

This study offers a conceptual and integrative framework that contributes to both theoretical and practical understandings of human-AI collaboration in the manufacturing sector. It identifies five core design principles: human-centered design, explainability and transparency, adaptive task allocation, strategic role definition, and hybrid intelligence, that form the basis for effective integration of AI technologies alongside human actors. These principles are not only theoretically grounded but also empirically substantiated through literature-based evidence of their practical benefits and implementation challenges.

The article's aim was to address a persistent research gap in the theoretical integration and modelling of human-AI interactions, particularly the lack of cohesive conceptual tools to assess whether AI and humans function as elements in symbiosis or as independent entities in manufacturing environments. Drawing on a semi-systematic literature review, the paper has successfully fulfilled this objective by developing a structured analytical framework that situates human-AI collaboration within the broader context of organizational, technological, and societal transformation. It explores the dynamic tensions and manifestations of interaction models: cooperative, supportive, and independent and links them to implications for system design, work organization, and long-term integration. Thus, the main research question has been answered, the findings confirm that human-AI relationships in manufacturing predominantly align with models of adaptive symbiosis rather than strict independence, while also highlighting challenges that hinder this integration.

Theoretically, the paper advances the field by reframing design principles as operational constructs rather than abstract prescriptions. It provides a vocabulary and structure for analysing the degree of coupling between human and AI agents, offering a differentiated view of how these relationships materialize in practice. In doing so, it enriches the theoretical discourse on socio-technical systems and contributes to a more granular understanding of hybrid intelligence in the industrial domain.

Practically, the framework provides valuable guidance for system designers, managers, and policymakers, enabling them to anticipate barriers such as system complexity and human-factor integration, while capitalizing on proven advantages like trust enhancement, flexibility, improved collaboration, and organizational readiness for artificial intelligence integration. For system designers, the results support the development of user-centered technologies aligned with human cognitive and operational capacities. For managers, the findings help inform strategic decisions on workforce transformation and process redesign. Policymakers can use the insights to shape regulations and incentives that foster responsible and effective AI adoption in manufacturing. The analysis confirms that successful human-artificial intelligence collaboration hinges on aligning technological design with human capabilities and organizational context. However, numerous challenges persist, including system-level

complexity, lack of structured implementation methods, risks of dequalification, and organizational resistance. These findings underscore the need for nuanced, context-aware approaches that go beyond mere technological optimization.

Despite these contributions, several limitations must be recognized. First, the study is based on a semi-systematic literature review, which, although methodologically rigorous, may have excluded relevant but unpublished or non-English sources. Second, the analysis relies primarily on secondary data from academic literature and does not include empirical field studies or firsthand accounts from manufacturing practitioners. Third, although the proposed framework is conceptually robust, it remains theoretical and has not yet been empirically tested or validated in real-world industrial settings. These limitations suggest caution in generalizing the findings and point to the necessity of further empirical exploration.

Future research should aim to operationalize and validate the proposed design principles in varied industrial environments through longitudinal case studies, controlled experimental research, and participatory design projects involving direct collaboration with end-users. Particular emphasis should be placed on sectors such as automotive manufacturing and precision engineering, where human expertise remains central and AI integration is advancing rapidly. There is also a clear need to deepen our understanding of system integration strategies, especially regarding data quality, interface transparency, and the dynamics of human-AI co-learning in high-stakes environments. Additionally, ethical and social dimensions of AI adoption such as worker participation, trust development, and long-term cognitive engagement-require more systematic, interdisciplinary investigation, combining insights from engineering, organizational science, and human factors. Such integrative efforts will be essential for developing actionable, sustainable, and ethically grounded models of human-AI collaboration.

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HUMAN RESOURCES MANAGEMENT IN AUTOMOTIVE SUPPLY CHAINS IN THE TIME OF THE FOURTH INDUSTRIAL REVOLUTION

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Purpose: The purpose of this paper is to explore the challenges and opportunities of managing a multi-generational workforce within cooperative enterprises undergoing digital transformation. The research aims to identify universal principles and suitable management methods that can be applied in organisations operating in the context of technological change, especially within the automotive supply chain. Special attention is given to bridging the digital competence gap among older employees and enhancing the relational competencies of younger generations.

Design/methodology/approach: This study adopts a mixed-methods approach combining literature review and empirical research. The theoretical framework is grounded in contemporary human resource management theories, generational theory, and digital transformation literature. The empirical part includes qualitative and quantitative analysis focused on multigenerational workforces across different levels of the automotive supply chain. The study identifies digital competence disparities and investigates how tailored management methods can address generational differences in digital skills and workplace expectations.

Findings: The research revealed significant differences in digital competences across generations, with older employees often facing challenges in adapting to new technologies, while younger employees demonstrate lower levels of relational and organisational loyalty. The findings suggest that successful human resource management in this context requires adaptive leadership, personalised development strategies, and intergenerational knowledge-sharing practices. The study provides a set of recommended management instruments aimed at enhancing digital inclusion and intergenerational cooperation.

Research limitations/implications: This research is limited in its scope to cooperative enterprises, primarily within the automotive sector, and may not fully generalise to other industries. Further research could expand the study to include non-cooperative or global corporations and apply longitudinal methods to assess the long-term effectiveness of the proposed management practices.

Practical implications: The study offers practical recommendations for managers of cooperative organisations on how to adapt HR practices to the needs of multigenerational teams. This includes designing training programs tailored to age-specific needs, promoting digital mentoring, and creating inclusive organisational cultures. The results can contribute to

increased employee satisfaction, productivity, and reduced generational conflict in digitally transforming workplaces.

Social implications: The paper highlights the importance of inclusive digital transformation and intergenerational solidarity in the workplace. By fostering mutual understanding and reducing digital exclusion among older employees, the research supports broader social goals such as social cohesion, active ageing, and responsible digital development. These practices can inform policies on workforce inclusion and generational equity.

Originality/value: This paper provides original insights into the intersection of generational diversity, digital transformation, and cooperative enterprise management. It offers a unique perspective by addressing management practices specifically tailored for multi-generational teams within cooperative structures and supply chains, contributing to both academic literature and managerial practice. The paper is intended for HR professionals, cooperative managers, policymakers, and scholars in organisational studies.

Keywords: multigenerational workforce, digital transformation, cooperative enterprises, human resource management, intergenerational management.

Category of the paper: Research paper.

Introduction

The reason for writing this article is the identified research gap in recommending methods for managing human resources in the era of the fourth industrial revolution. In order to identify the research gap, a review of recent global literature (publications from 2017-2024) focused on competencies 4.0 of a multigenerational and multicultural workforce was conducted. The surveyed literature on HR management in the era of the fourth industrial revolution is mainly concerned with the contexts of HR and technology implementation, change management in a transitioning company. Meanwhile, there is a dearth of publications on supporting managers during the challenging period of digital transformation of companies and their supply chains. Recognising this literature gap, the research sought to answer the questions:

- What management methods to recommend in a multigenerational work environment in the era of the fourth industrial revolution?
- What management methods to recommend in a multicultural (combining the cultures of multiple organisations working together in a supply chain) work environment in the era of the fourth industrial revolution?

The literature study provided an overview of selected management methods: - the identification of the strengths and weaknesses of these methods applied in organisations undergoing digital transformation (the strengths and weaknesses of these methods were identified in the context of managing the workforce of generations: X, Y, Z); - identification of the strengths and weaknesses of these methods applied in organisations undergoing digital transformation (the strengths and weaknesses of these methods were identified in the context of personnel management at different levels of supply chains). After the literature analysis,

it was confirmed that there is generational and cultural diversity. Confidence was gained that a manager needs to take generational and cultural diversity into account through the use of preferred management methods.

In carrying out the self-study, the research question was again posed, namely: What management methods to recommend in a multigenerational work environment in the era of the fourth industrial revolution? What management methods to recommend in a multicultural work environment in the era of the fourth industrial revolution? The research objective was to identify the differences arising from the digital competences of different generations, which are highlighted in companies belonging to supply chains undergoing digital transformation.

The aim of the application was to try to match methods and instruments that would support managers in managing human resources from different generations, but also from different organisations. Particular attention was paid to recommending management methods and instruments that compensate for digital competence gaps in older generations and relational competence gaps in younger generations. Two research hypotheses were put forward:

1. Generational diversity concerns mainly digital and relational competences.
2. A manager can use known management methods with new instruments to effectively compensate for identified competence gaps.

Literature review

The chapter entitled 'Literature review' contains a systematic review of the literature. A systematic literature review is a method of integrating research evidence that uses explicit methods to identify, select, critically appraise and analyse data from relevant studies qualified for review. The literature for the review was categorised according to keywords, i.e. human resource management, management methods, multigenerational workforce, multicultural/interorganisational workforce, digital transformation. Evidence was selected that demonstrates the feasibility of using the selected methods to manage a multigenerational and multicultural workforce. The literature reviewed systematically was published over a period of many years, i.e. from 1987 to 2024. Such a period of time confirms the utilitarian nature of the management methods described, but also the universal principles that should guide a manager managing a multigenerational and multicultural (from different cooperating organisations) workforce in times of difficult economic transition.

A Technologies introduced into the business processes of enterprises require new predispositions and skills from human resources. Selected literature studies have analyzed the key dimensions: education and qualifications of employees (Benesova et al., 2017); key employee skills required of workers in the era of the fourth industrial revolution. In addition to the need for competence in digitization, AI, robotics and big data (Sima et al., 2020),

soft skills (Pejic-Bach et al., 2020), a disposition for continuous training (Flores et al., 2020) and flexibility and a collaborative attitude (Matt et al., 2020) are essential. Some studies have looked at the relationship between social trends and Industry 4.0 technologies (Bednar, Welch, 2020). Researchers have highlighted the changing demographics of the workforce in the context of Industry 4 challenges (Calzavara et al., 2020; Javaid, Haleem, 2020). The researchers, seeing that the demographics of the workforce are changing (there is a general aging of the population and a higher average age of the workforce worldwide), found it worthwhile to study the relocation and distribution of work (remote and smart work) in this context (Calzavara et al., 2020; Garay-Rondero, Martinez-Flores, Smith, Caballero Morales, Aldrette-Malacara, 2020).

Other works have emphasized that the introduction of Industry 4.0 systems and technologies entails opportunities and pitfalls for organizations and management (Benesova, Tupa, 2017; Nahavandi, 2019; Xu et al., 2021). Like any transition to a new production paradigm, a new organization of business processes, leadership styles and personnel management methods is required. Educating and qualifying managers (Benesova et al., 2017); managing human-machine interaction, i.e., the connections between the mind of a (human) worker and the (artificial) intelligence of robots to increase collaboration and reduce competition is a new challenge for managers (Nahavandi, 2019; Xu et al., 2021). Extreme connectivity between organizations, employees, workers and robots in a digitized organization creates new social power structures. Existing management methods, may no longer be acceptable in digitally transformed enterprises, may lead to various personnel problems, authoritarian rule by one person. Researchers say that new management methods should be proposed in the social sciences and humanities for effective and efficient implementations of Industry 4.0 and 5.0 technologies (Dezi et al., 2018; Ozdemir, 2018) especially in multi-generational environments.

Management methods used in multigenerational work environments in the era of digital transformation.

Management by communication – Essence of the method

The main features of this method are: exposure (in the organisational structure of cooperating companies) of positions and cells oriented to information and communication processes; use of a rich spectrum of different methods and means of information and communication; improvement of information and management processes leading to the improvement of the existing information and communication system in the supply chain. The method implies personalised information for employees of different organisations (operating in the supply chain) and who are at different levels (from the highest - the board of directors and company management, through functional department managers, to specialist positions in different fields). Significant emphasis is also placed on the use of information technology as a tool to support the implementation of management by information and communication (Durach, Machuca, 2018). Personal communication is the driving force behind supply chain integration (Wang, Kang, Childerhouse, Huo, 2018).

- Communication barriers of generation X; Communication expectations of generation X

In the process of creating the right communication environment with Generation X, the manager should pay attention to the fact that their representatives value direct 'face-to-face' contact much more. Personal attachment, personal credibility and personal communication influence the integration of collaborators in the supply chain (Wang, Kang, Childerhouse, Huo, 2018). Therefore, information exchange via instant messaging may not be effective (Wasylewicz, 2016). However, this does not mean that X are completely closed to new technologies. Phone calls and emails are acceptable, but should not dominate during active meetings. Email is an effective form of information exchange. Sharing information via social media can make X feel uncomfortable and distracted (Rogulska, 2018).

- Communication barriers of generation Y; Communication expectations of generation Y

Generation Y is one of those generations that value face-to-face contact, but are equally keen to use modern forms of remote communication. Generation Y values a good atmosphere at work. They function much better in flat organisational structures that allow freedom of communication between employees of cooperating companies. Communicating praise has a positive effect on Y. They take criticism less well, so every effort should be made to ensure that communicating mistakes does not cause them stress. Y are advocates of feedback. Managers can use IT tools, such as collaboration platforms, while maintaining attention to trust and openness.

- Communication barriers of generation Z; Communication expectations of generation Z

Managers increasingly perceive a problem with building an appropriate channel for exchanging information with Generation Z employees. Deficits in telephone communication affect the reduced level of satisfaction with duties performed to improve supply chain flows. Generation Z, on the other hand, is perfectly comfortable using inter-organisational instant messaging, where everything can be communicated to everyone. Quick feedback from IT systems and rapid data collection via AI is preferred by Generation Z. Young people also appreciate being able to communicate in a way that is relevant to their trends in language, words etc. Therefore, it is worth trying to delve into the topic of phrases, to create a conducive environment for professional communication (Sulyma, 2022).

Management by delegation – essence of the method

Management by delegation should be properly defined as the delegation of authority, duties and responsibilities (Niemczyk, 2000) and should be classified as a method for motivating employees. The essence of delegation of authority is the transfer of specific decision-making capacities together with the burden of these decisions from the supply chain management agency to employees of other cooperating organisations (Partyka, 2022). When observing the work carried out by agency managers, it can often be seen that the number of tasks assigned to them can cause numerous overloads due to the temporal overlap of individual responsibilities. The accumulation of such a number of activities to be carried out can negatively affect productivity and the achievement of positive supply chain results. By delegating tasks to

employees of cooperating organisations, trust is simultaneously shown. This builds the employees' sense of worth and increases their willingness to cooperate. It allows the employee to identify with the results of the project and builds awareness that the role played in the implementation of a particular project was important for the proper functioning of the supply chain (Timescu-Dumitrescu, 2019).

- Effective delegation to generation X

Employees belonging to Generation X highly value the role of agency in the supply chain (Fayezi, O'Loughlin and Zutshi, 2012) and the opportunity to make independent decisions. They want to have a say in the final implementation of tasks. For this reason, the delegation process itself should be set up in a way that allows active participation in decisions related to delegated responsibilities. X like to feel responsible for tasks. In the delegation process for Generation X, it is also important to consider the possibility of adapting the schedule of delegated work to individual preferences. The need for flexibility in their approach to responsibilities will affect their effectiveness and satisfaction with their delegated work (Kronke, 2015).

- Effective delegation to generation Y

Generation Y are very good candidates for delegating tasks to be performed in inter-organisational teams. For them, interacting with other employees on projects is an opportunity to exchange knowledge, gain new experiences and develop interpersonal skills. The process of delegation should be closely linked to opportunities to promote supply chain improvement activities. Delegation from agencies should include regular feedback to enable them to track progress, understand what they are doing well and what they can still improve. Specific messages reflecting perceptions of their work will stimulate their engagement and ongoing professional development. They are digital natives, which means they are very familiar with modern communication tools. It makes sense to use new technologies in the delegation process, taking into account their preference for using modern platforms, apps or tools for effective communication and delegation (Kronke, 2015).

- Effective delegation of tasks to generation Z

Delegating responsibility for a task should be communicated in an appropriate way so that the employee understands its context and purpose. Coding the delegated task will be easier for the young employee if every little detail is explained to them. The explanation should include information such as how to perform the task, the purpose of the task, the idea of the final result. It is advisable to systematically consult the results of each stage of the activity, as feedback is very important for generation Z. When performing a duty, it is important to listen to their dilemmas or suggestions that they think should improve the whole process. Creating a space to express the employee's thoughts and suggestions creates an attractive working environment for Z. In addition to paying attention to the above-mentioned aspects of effective delegation, modern communicators should be used. An interesting way to make employees more effective is to set a deadline that is embedded in a specific time. It is necessary for the manager to make

sure that the employee understands what needs to be done. To do this, the employee can be encouraged to provide their interpretation of the task received. When the implementation of the instruction is successful, the agency manager should reward those involved, using, for example, verbal praise and celebration of success (Zubelewicz, Kardasz, 2017).

Management by motivation – essence of the method

Management by motivation aims to make employees perform tasks under the influence of various incentives. There are many different approaches and ways to motivate employees, such as rewards, employee evaluations and punishment systems. It is also important to understand the needs and goals of employees and to create an appropriate motivational system. The effectiveness of motivation systems in companies but also in supply chains depends on the values and preferences of employees (Gellerman, 1968; Birou, Hoek, 2022). Satisfying the motivational needs of employees is a difficult task for managers of super organisations (Fantozzi, Di Luozzo, Schiraldi, 2024). It is important to remember that the employee of each supply chain organisation may respond differently to motivational incentives, which often becomes a test of managerial creativity. An incentive system for the entire supply chain workforce requires the identification of a set of soft skills and capabilities that determine success in the chosen industry. The identified soft skills and capabilities can help to develop specific motivators for individual jobs.

- Supporting the development of Generation X through management by motivation

Generation X is characterised by specific values and soft skills that influence their approach to work, relationships. X are loyal employees who identify with the company and supply chain they work for (Syper-Jędrzejak, 2014). Managers should focus on building and nurturing a supply chain community, developing programmes to encourage inter-organisational collaboration, organising team-building events or offering opportunities to share generational and intergenerational experiences. This generation needs to be motivated by declaring their contribution to supply chain teamwork. Rewarding individuals and teams for their contribution to supply chain integration can increase engagement and also create an atmosphere where everyone feels important. In addition, recognising employee engagement through rewards increases commitment (Smolbik- Jęczmień, Żarczyńska-Dobiesz, 2017).

- Supporting the development of generation Y through management by motivation

For Generation Y people, maintaining a work-life balance is crucial. They tend to take on tasks that give them satisfaction and allow them to achieve their goals. At the centre of their motivation are primarily intangible incentives (Syper-Jędrzejak, 2014). By offering flexible work options, such as remote working or flexible working hours, representatives of generation Y can better manage their time and personal lives, which increases their motivation to perform their professional duties. By allowing this generation to choose more flexible tasks, tailored to individual skills and preferences, employers can achieve greater productivity. Creating a work environment where employees can focus on cross-organisational projects can significantly increase engagement. Investment in professional development, including training, mentoring

and career development programmes, can be a strong source of motivation for Generation Y (Smolbik-Jęczmień, Żarczyńska-Dobiesz, 2017).

- Supporting the development of Generation Z in the application of management by motivation

The use of coaching methodologies in the supply chain makes it possible to help employees increase their productivity and support them to work cooperatively. Generation Z focuses on skills and developmental outcomes. They value scheduled sessions with an expert, as well as supportive conversations. Conversations are seen as a way to cope with robotisation, organisational change and uncertainty (Gran, 2016). Mentoring provides an opportunity to pass on skills and knowledge acquired by a more experienced expert. The mentor is a role model for generation Z and helps to directly diagnose emerging issues (Connor, Pokora, 2017). Mentoring is a form of motivation for generation Z. An external counsellor can be engaged to improve supply chain performance. Psychological counselling is increasingly needed to provide support in stressful situations and for developmental progress (Mcleod, Henderson, 2003).

Management by delegation of authority and controlling – essence of the method

Controlling is an effective management method. The instruments adopted in controlling (e.g. KPIs) improve management. The use of controlling solutions is possible thanks to the data collected, transformed into information. Based on the information, strategic, tactical and operational plans are built. Employees performing assigned tasks and meeting KPIs are also controlled (Fantozzi, Di Luozzo, Schiraldi, 2024). The employee should act according to set standards, but in order for the manager to be sure that the action is performed, he or she exercises control (Dědečková, 2020). Control also serves the employee by giving a sense of correctly performed tasks. Controlling the correctness of tasks complemented by controlling other parameters, such as time, influences the evaluation of the employee. Control and evaluation can become a source of inspiration to perform assigned tasks more conscientiously and be a source of satisfaction with tasks well performed (in the case of positive performance evaluation). Controlling intellectual capital in the supply chain contributes to improving supply chain performance supports seamless chain integration (Mubarik and Khan 2024). The authors argue and argue that supply chain management by controlling human labour is a strategic component when implementing and operating a supply chain.

- Redesigning the control process for generation X

The importance of autonomy and independence at work is evident for Generation X. Generation X representatives have a relaxed approach to carrying out their duties, which allows them to approach tasks individually and make decisions independently. As such, they require a flexible approach to tracking progress. They prefer to work in a way that allows them to manage their time and tasks according to their preferences. When assessing their performance, it is useful to maintain clear standards and benchmarks (e.g. KPIs) that can motivate them to achieve their goals. In addition, periodic appraisal meetings, provide an opportunity to discuss progress, set new goals and receive constructive feedback (Wasylewicz, 2016). For Generation

X, finding a balance between autonomy and support from collaborating organisations is crucial. Flexible forms of monitoring, performance appraisals and developmental conversations create a holistic approach that suits their preferences and promotes productivity and professional development.

- Redesigning the control process for generation Y

Employees of the Millennial - Y generation expect continuous feedback as part of their ongoing supply chain development efforts. By receiving regular feedback on performance, they can adjust their results, respond quickly to changes and achieve their goals. However, in addition to feedback, it is important to recognise their contribution to achieving the goals of the organisation and the supply chain they work for. Recognising them as key players in the success of the company is a great motivator and increases their value. Periodic progress monitoring is another factor that this generation values. Millennials prefer a variety of performance appraisal tools and methods, from traditional meetings to digital tools that allow them to tailor the appraisal process to their needs and work style (Gadomska-Lila, 2015).

- Redesigning the control process for generation Z

When undertaking review activities, it is important to remember that they will be linked to the employee's expectations (feedback expectations). The younger generation feels more engaged if the control ends with specific feedback on whether they are satisfied or dissatisfied with their work, allowing them to make changes/improvements. Therefore, KPIs may not be sufficient for this generation. Generation Z is waiting for a detailed answer on what needs to be changed in the supply chain and how to avoid the risks of the future (Swierkosz-Hołysz, 2016). The feedback message must bluntly represent the manager's intention. Communicate the message in a sincere and concrete way, referring only to the behaviour in question and not personally (Niermeyer, 2009).

Management by objectives – essence of the method

Management by objectives is a method of building a coherent set of objectives for all cells and collaborating organisations and assessing the level of achievement (Carrolls, 1978). The assumption is that the supervisor and his subordinates agree on objectives that will be valid for a certain period of time. And in a supply chain, its links agree on the chosen objectives. Co-creation of objectives in the supply chain can bring many benefits. The maturity of supply chain management means that goals are set for the implementation of Industry 4.0, environmental management and product management (Vasconcelos, Sigahi, TFAC, Pinto, Rampasso, Anholon, 2023). An employee who is made aware of supply chain objectives feels responsible for achieving them. Knowledge of the objectives exerts additional motivation and focus on the tasks to be performed. An employee involved in planning shows integrity and ambition (Thomson, 1998).

- Goal setting for generation X

Generation X values the opportunity to shape their own career path, which means that supply chain goals should be transposed to their individual career aspirations. The goal-setting process for Generation X should take into account their need for autonomy and self-reliance. Goals that elicit the commitment of Generation X are those that allow them to develop their individual skills, allow them to gain experience, and at the same time are in line with the overall goals of the super-organisation. The goal-setting process requires open communication and dialogue, in which employees have the opportunity to express their personal opinions and career goals, and the organisation can flexibly adjust its expectations. Flexibility in achieving goals is a key aspect for Generation X. They want to know the methods and deadlines for achieving goals that fit into their work pace and personal lives. Employees of this generation value the ability to decide how and when they achieve goals (Smolbik-Jęczmień, 2013).

- Building an organisation's goals and personal development plan for Generation Y employees

Generation Y is one of those individuals who focus on the pursuit of achievement, satisfying results and setting ambitious goals (Warwas, Wiktorowicz, Jawor-Joniewicz, 2018). An individual development plan for employee Y is closely linked to the identification of specific development goals, the preparation of a schedule that includes a series of training courses that provide opportunities to acquire knowledge and skills that are attractive in the workplace. The schedule allows for the identification of individual goals and their achievement through consistency with company and supply chain objectives (United States Nuclear Commission, 2008). During the initial phase, strengths, interests, inspirations and development paths should be identified. The manager should focus attention on activities and behaviours that determine the willingness to commit to the company's goals. The next step should be to identify competences and skills based on work experience and acquired knowledge. An employee's career path developed in this way will contribute to the success of the organisation and the entire supply chain. Discussing and analysing company/supply chain performance in the context of employee development is the essence of management by objectives for generation Y.

- The use of gamification in achieving goals by generation Z

An interesting solution to increase employee involvement in supply chain development is so-called gamification. This tool is not related to the use of computer games, but to the use of mechanisms specific to games. Gamification causes the employee to achieve goals in an interesting way, without causing competitive stress. This tool is particularly recommended for managing the goals of staff in departments such as purchasing, warehouses (Khan, Kumar, Singh, Ashraf, 2024). Clear feedback on performance and visualisation of results is highly valued by young people. In addition, with high performance, the player/employee can expect a reward, which in turn builds their confidence and self-esteem. Using gamification, employee behaviour can be targeted. Scoring can be used in evaluation, in which optimising supply chain

processes will be rewarded. Generation Z expects to organise competitions with rankings, picking winners, culminating in bonuses (which can be organised collectively for selected employees across the supply chain).

Managing with organisational culture – the essence of the method

The success and broader performance of supply chain activities depend not only on the managerial skills of the management and the material and financial resources available. They also depend on the hard-to-define atmosphere, style of behaviour, development history of the cooperating companies, their technical level, management style, demographic and psychological characteristics of the employees, adopted patterns of behaviour, and together they form what we call organisational culture. Considerations by many authors have shown that organisational culture results from the management method used (Kinar, 2022). Organisational culture is built by the values that guide the manager. Organisational culture sets the standards for quality performance and ethical behaviour. Any attempt to modify or change the organisational culture becomes an opportunity for supply chain development (Davis, Dolson, 2018). Executives have a decisive influence on the development of organisational culture, as every managerial action, gesture and attitude is closely observed by employees (Zanon, Sigahi, Anholon, Carpinetti, 2024).

- Important elements of organisational culture for generations X, Y, Z

Given how different each generation is, one could put forward the theory that this diversity will also be evident in the importance of organisational culture. Each generation has experienced different social, cultural, political, etc. situations that have become decisive factors in shaping their worldview, values and needs for their working life. However, it turns out that despite so many differences, there is something that unites each generation. Empirical research shows that, regardless of the age of the respondents, they shared a common opinion that the best choice for their personal beliefs is the so-called clan culture (Wziątek-Staśko, 2019). By obtaining such data, it can be concluded that every employee, regardless of age and experience, needs to be in a place with a familial and friendly atmosphere, focused on the common achievement of set goals. In a clan culture, team activities are paramount. Where there is cooperation, people feel valued (Wyrwicka, 2014). Issues of loyalty, trust and building shared prosperity are important to people (Kot, 2016). Supply chain researchers deconstruct the organisational culture of individual organisations into key elements and provide directives for action plans for improvement (Zanon, Sigahi, Anholon, Carpinetti 2024). They provide example applications to guide and promote the application of a coherent organisational culture for the supply chain. One should consider whether such applications should be prepared with the differing generations X, Y, Z in mind.

Research methodology

The next chapter, 'Research results', presents the results of secondary (i.e. prepared by the research organisations) and primary (i.e. collected through a prepared questionnaire) data research. The secondary data research (prepared by the European Commission, Digital Economy and Social Index 2020) showed generational differences in digital competences across countries, industries, professions, generations. When conducting the primary research for this article, it was determined that the subjects of the research would only be professionals from different generations working in companies in the automotive industry. It is worth mentioning that specialists coming from companies belonging to supply chains, (being at different levels of supply chains) were studied. The professionals were selected using the quota selection method. This means that they had to meet criteria in order to be included in the study (their job title had to be ds.... specialist, they had to be employed in an automotive industrial company, they had to specify whether they were a first, second...tier supplier). Quota selection in this study meant that specialists from all generations X, Y, Z were surveyed in numbers proportional to the total number of employees in the labour market. However, in the end, after setting the sample size at 150 people, it was decided to keep the same number of respondents in the groups belonging to generations X (50 people), Y (50 people), Z. The research method was statistical. The research technique was a survey, the research tool a prepared survey questionnaire. The questionnaire was distributed via the google portal (<https://www.google.pl/intl/pl/forms/about/>). The preparation of the research tool was dictated by the aim of the study, which was to identify the differences arising from the digital competences of the different generations that are highlighted in companies undergoing digital transformation. In preparing the survey tool, an attempt was made to confirm the assumptions that: 'generational diversity is mainly about digital and relational competences' and "the manager can use familiar management methods with new instruments to effectively compensate for identified competence gaps". The data collection lasted from May to June 2024. The analysis of the collected data is presented in chapter: Research findings.

Research results

The following charts show that in the working environment of many EU countries, a digital competence gap of cadres is emerging compared to the cadres of the countries - leaders of the ranking. Figure 1 shows the Ranking of EU countries according to the Digital Economy and Digital Society Index (DESI, 2000).

Table 1.
Legend for figure 1

Communication	Human capital	Use of digital technologies	Use of digital technologies	Digital public services

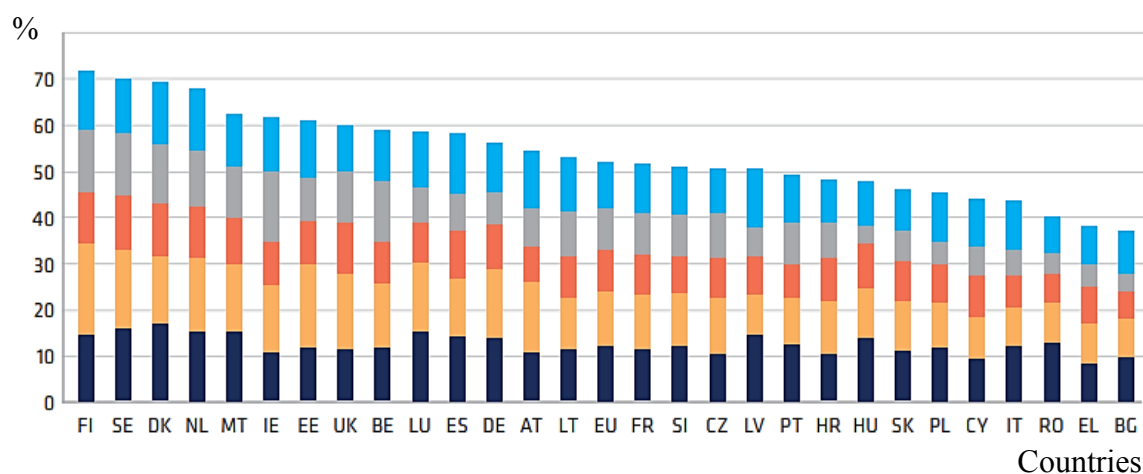


Figure 1. Ranking of EU countries according to the digital economy and digital society index (DESI, 2000).

Source: the European Commission, Digital Economy and Social Index (DESI, 2020), https://arp.pl/documents/41/Kompetencje_cyfrowe_ARP_part_I.pdf

Figure 2 shows the assessment of digital competence of residents in the European Union countries.

defect	basic	low	higher

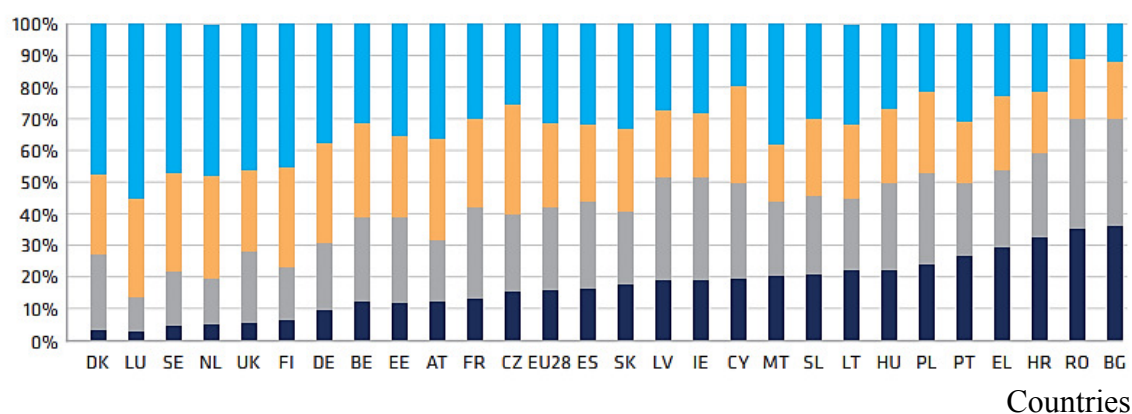


Figure 2. Assesses the digital competence of residents in the European Union countries.

Source: the European Commission, Digital Economy and Social Index (DESI, 2019), https://arp.pl/documents/41/Kompetencje_cyfrowe_ARP_part_I.pdf

Table 2 shows the assessment of digital competence of EU employees of selected professions by level of competence.

Table 2.

Evaluation of digital competencies of EU employees of selected professions (by level of competence)

Occupation performed	Competence level	Percentage of employees (%)
Manager	Basic	8.3
	Advanced	18.7
	Specialized	23.3
Specialist	Basic	38.4
	Advanced	8.9
	Specialized	10.3
Technician	Basic	40.5
	Advanced	9.8
	Specialized	11.8
Office worker	Basic	56.8
	Advanced	13.2
	Specialized	14.1
Machine operator	Basic	27.5
	Advanced	7.1
	Specialized	4.7
Worker	Basic	35.1
	Advanced	7.5
	Specialized	5.7

Source: the European Commission, Digital Economy and Social Index (DESI, 2016), https://arp.pl/documents/41/Kompetencje_cyfrowe_ARP_part_I.pdf

The evaluation of the competence of industrial enterprise specialists by level of sophistication shows that 38.4 percent of them declare basic digital competence, only 10.3 percent of specialists evaluate their digital competence as specialized.

Table 3 shows the evaluation of digital competencies of Polish residents against the EU in age ranges.

Table 3.

Assessment of digital competencies of Polish residents against the EU in age brackets

Age range (years)	Digital competences (%)					
	Low		Basic		Specialized	
	EU	PL	EU	PL	EU	PL
16-24	15	14	25	37	57	48
25-34	21	23	29	38	46	35
35-44	27	37	29	30	36	24
45-54	30	39	29	22	27	11
55-64	31	31	25	14	16	5
65-77	26	20	18	6	7	2
Total populations	26	28	26	25	31	21

Source: the European Commission, Digital Economy and Social Index (DESI, 2016), https://arp.pl/documents/41/Kompetencje_cyfrowe_ARP_part_I.pdf

The table presented does not show an assessment of the digital competence of professionals employed by industrial companies by generational groups. However, the population data presented in the table confirms quite a disparity in the digital competencies of different age groups.

The following Table 4 presents the qualifications and skills important from the point of view of an Industry 4.0 employee.

Table 4.*Qualifications and skills important from the point of view of an Industry 4.0 worker*

Knowledge of information and communication technologies	Ability to work with data
• Basic IT knowledge • Ability to use and interact with intelligent machines • Understanding of machine-to-machine communications, data protection and cybersecurity	• Ability to process and analyze data received from machines • Understanding of data entry, visualization and decision making processes • Basic knowledge of statistics
Know-how	Personal skills
• Interdisciplinary and generic knowledge of technologies • Specialized and generic knowledge of factory operations and production processes • Technical know-how about the machines necessary to operate them	• Ability to adapt in the workplace and readiness for change • Ability to work in a team and willingness to share knowledge • The ability to change the way of thinking under the influence of science

Source: Aulbur, Arvind, 2016, p. 123.

A study of the literature (Stawiarska et al., 2019, 2021, 2024) made it possible to prepare Table 5. Table 5 groups the competencies of the 4.0 specialist employee so that the manager can support/develop them using specific management methods.

Table 5.*Management methods, and developing new competencies of the employee*

Management method by:	Qualifications and skills important from the point of view of an Industry 4.0 employee and developed by the management method
communicating	• communication competences using instant messengers • the ability to use and interact with computers and intelligent machines • data protection and cybersecurity understanding/skills
motivating	• ability to adapt in the workplace and plan development in the context of digital transformation • readiness for changes regarding digital transformation / involvement in the digital transformation process • creativity in implementing increasingly better digital solutions
delegation of authority and controlling	• interdisciplinary and generic knowledge of technologies and know-how about machines necessary to operate them • specialized and generic knowledge of factory operations and production processes • ability to make decisions regarding digital transformations
goals	• ability to analyze and process data received from machines • ability to enter visualization data and make decisions based on data • generic knowledge of business statistics
building organizational culture	• ability to adapt in the workplace and readiness for change • ability to work in a team and willingness to share knowledge • the ability to change the way of thinking under the influence of science

Source: own study.

The following takes a closer look at each of the management methods, attempts to identify new 4.0 instrumentation that can support the chosen method, and presents the results of our own research (based on primary data obtained through a questionnaire).

Management by communication – Essence of the method in the era of Industry 4.0

In the era of Industry 4.0, an important emphasis in the application of this method is the use of ITC as a tool to support communication, data generation and processing, work scheduling and performance measurement (Wang, Kang, Childerhouse, Huo, 2018). New competencies

(relevant to supply chain integration) developed using this method (using modern ITC technology tools) are:

- communication competence using instant messaging,
- the ability to use and interact with computers and smart machines,
- understanding/skills regarding data protection and cyber security.

The results of the self-assessment of the specialists - employees of industrial companies in the automotive sector are presented in Tables 6-8.

Table 6.

Results of the self-assessment of specialists - employees of industrial enterprises in the automotive sector with regard to communication competences using instant messaging

How do you assess your communication competences using instant messengers?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	20	1	3	1	0
Advanced	2	18	2	39	2	5
Specialized	3	12	3	8	3	45
Weighted arithmetic mean	1,84		2,1		2,9	

Table 7.

Self-assessment results of specialists – employees of industrial enterprises in the automotive industry in terms of skills in operating computers and intelligent machines and the ability to cooperate with them

How would you rate your ability to use and interact with computers and intelligent machines?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	11	1	18	1	30
Advanced	2	23	2	19	2	15
Specjalized	3	16	3	13	3	5
Weighted arithmetic mean	2,1		1,9		1,5	

Table 8.

Self-assessment results of specialists – employees of industrial enterprises in the automotive sector in terms of knowledge/skills in data protection and cybersecurity

How do you rate your understanding/skills regarding data protection and cybersecurity?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	45	1	30	1	32
Advanced	2	5	2	15	2	16
Specjalized	3	0	3	5	3	2
Weighted arithmetic mean	1,1		1,5		1,4	

Management by motivation - Essence of the method in the era of Industry 4.0

In the era of Industry 4.0, an important accent in the application of this method is the use of motivational systems based on gamification. Mobile applications for the coworking community are also used, introducing interesting solutions, comparing the results of various tasks, organizations or employees (Fantozzi, Di Luocho, Schiraldi, 2024). Such motivation, especially

for the young generation, has become a support for rebuilding interpersonal relations. New competences developed through the use of the motivational management method are:

- adaptability in the workplace and development planning in the context of digital transformation,
- readiness for changes related to digital transformation / involvement in the digital transformation process,
- creativity and competition in implementing increasingly better digital solutions.

The results of the self-assessment of specialists - employees of industrial enterprises in the automotive industry are presented in Tables 9-11.

Table 9.

Results of the self-assessment of specialists - employees of industrial enterprises in the automotive industry in the field of adaptability in the workplace and development planning in the context of digital transformation

How do you assess your ability to adapt in the workplace and plan for growth in the context of digital transformation?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	10	1	5	1	42
Advanced	2	19	2	15	2	4
Specjalized	3	11	3	30	3	4
Weighted arithmetic mean	1,62		2,5		1,24	

Table 10.

Results of self-assessment of specialists - employees of industrial enterprises in the automotive industry on readiness for change regarding digital transformation / commitment to the process of digital transformation

How would you rate your readiness for change regarding digital transformation / commitment to digital transformation?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	31	1	12	1	2
Advanced	2	15	2	25	2	16
Specjalized	3	4	3	5	3	32
Weighted arithmetic mean	1,46		1,54		2,6	

Table 11.

Results of self-assessment of specialists - employees of industrial enterprises regarding creativity in implementing better and better digital solutions

How do you rate your creativity in implementing better and better digital solutions?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	45	1	30	1	20
Advanced	2	5	2	15	2	16
Specjalized	3	0	3	5	3	14
Weighted arithmetic mean	1,1		1,5		1,56	

Management by delegation of authority and controlling – Essence of the method in the era of Industry 4.0

In the era of Industry 4.0, an important element of applying this management method in supply chains is the use of integrated IT systems of the MRP, DRP, CRM class (Fantozzi, Di Luo, Schiraldi, 2024). Thanks to these systems, delegating authorizations is simple, and the decision-maker signs documents in the system with their marker/signature. In the era of implementing AI to optimize supply chains, new technology supports decision-makers in making decisions. Using blockchain, supply chain employees confirm their contribution. New competences developed through the use of the delegation management method (using modern technological tools of Industry 4.0) are:

- interdisciplinary and general knowledge of technologies and know-how of machines necessary to operate them,
- specialist and general knowledge of factory operations and production processes,
- ability to make decisions in the field of digital transformation.

The results of the self-assessment of specialists - employees of industrial enterprises in the automotive industry are presented in Tables 12-14.

Table 12.

Self-assessment results of specialists - employees of industrial enterprises in the automotive industry in the field of interdisciplinary and general knowledge of technologies and know-how of machines necessary to operate them

How would you rate your comprehensive and ever-expanding knowledge of the technologies and machine know-how necessary to operate them?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	15	1	10	1	28
Advanced	2	25	2	22	2	17
Specjalized	3	20	3	28	3	4
Weighted arithmetic mean	2,5		2,76		1,48	

Table 13.

Results of self-assessment of specialists - employees of industrial enterprises regarding specialized and generic knowledge about activities and production processes in the factory

How do you rate your comprehensive and constantly deepened knowledge of factory activities and processes?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	1	1	10	1	32
Advanced	2	5	2	35	2	16
Specjalized	3	44	3	5	3	2
Weighted arithmetic mean	2,86		1,9		1,4	

Table 14.

Results of self-assessment of specialists - employees of industrial enterprises regarding the ability to make decisions related to digital transformation

How do you rate your ability to make decisions regarding digital transformations in your company?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	45	1	30	1	36
Advanced	2	5	2	15	2	10
Specjalized	3	0	3	5	3	4
Weighted arithmetic mean	1,1		1,5		1,36	

Management by objectives - The essence of the method in the era of Industry 4.0

In the era of Industry 4.0, an important element of this method is the use of analytical systems using large data sets from inside the company and from outside (supply chain, economic environment) (Khan, Kumar, Singh, Ashraf, 2024). Some of the data used comes from radio beacons operating in BLE technology, others from satellites operating in GPS technology, still others from KPA KPI generating information based on artificial intelligence (Przegielński, Jemielniak, 20023; Marr, 2022). New competences developed through the use of the management by objectives method are:

- the ability to analyze and process data received from machines,
- the ability to introduce data visualization and make decisions based on data,
- general knowledge of business statistics. The results of self-assessment of specialists - employees of industrial enterprises operating in the automotive industry are presented in Tables 15-17.

Table 15.

Results of self-assessment of specialists - employees of industrial enterprises from the automotive industry in terms of the ability to analyze and process data received from machines

How do you rate your ability to analyze and process data received from machines?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	0	1	5	1	32
Advanced	2	5	2	10	2	16
Specjalized	3	45	3	35	3	2
Weighted arithmetic mean	2,9		2,6		1,4	

Table 16.

Results of self-assessment of specialists - employees enterprises from the automotive industry regarding the ability to enter data visualization and make decisions based on data

How do you rate your ability to enter data, visualize and make decisions based on data?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	25	1	20	1	30
Advanced	2	15	2	15	2	15
Specjalized	3	10	3	15	3	5
Weighted arithmetic mean	1,5		1,9		1,5	

Table 17.

Results of self-assessment of specialists - employees enterprises from the automotive industry regarding generic knowledge of business statistics

How do you rate your knowledge of business statistics?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	45	1	30	1	42
Advanced	2	5	2	15	2	6
Specjalized	3	0	3	5	3	2
Weighted arithmetic mean	1,1		1,5		1,2	

Management by means of organisational culture - Essence of the method in the era of Industry 4.0

The considerations of many authors have shown that organizational culture influences the management methods used (Kinar, 2022) and vice versa, the management methods used shape the organizational culture. Organizational culture is also built by the values that the manager professes. In the era of Industry 4.0, remote work, open innovation, digital twins of production processes, it is necessary to deal with the construction of e-culture (Bulińska-Stangrecka, 2018). An important accent in the application of the management method using e-culture is shaping the values of a virtual organization, in which the social responsibility of employees is emphasized. In an open, dynamic virtual organization, the manager encourages, enables and ensures safe sharing of knowledge, encourages creative work, inspires risky behavior, and all this through intelligent IT systems (Pol, 2022; Zanon, Sigahi, Anholon, Carpinetti 2024).

New competences developed through the use of this method are:

- the ability to adapt to a digital workplace and readiness for digital change,
- the ability to work in a team on digital solutions and the willingness to share knowledge,
- the ability to change the way of thinking under the influence of learning.

The results of the self-assessment of specialists - employees of industrial enterprises in the automotive industry are presented in tables 18-20.

Table 18.

Self-assessment results of specialists - employees of automotive industry enterprises in terms of adaptation to the digital work environment and readiness for digital change

How would you rate your ability to adapt in a digital workplace and your readiness for digital change?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	10	1	5	1	32
Advanced	2	19	2	15	2	14
Specjalized	3	11	3	30	3	4
Weighted arithmetic mean	1,62		2,5		1,44	

Table 19.

Self-assessment results of specialists – employees of automotive industrial enterprises in terms of teamwork skills on digital solutions and willingness to share knowledge

How do you rate your ability to work in a team on digital solutions and your willingness to share knowledge?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	19	1	5	1	34
Advanced	2	10	2	15	2	12
Specjalized	3	11	3	30	3	4
Weighted arithmetic mean	1,44		2,5		1,4	

Table 20.

Self-assessment results of specialists - employees of automotive industrial enterprises in terms of their ability to change their way of thinking under the influence of learning

How do you rate your ability to change your way due to learning?						
degree	Generation X		Generation Y		Generation Z	
Basic	1	10	1	5	1	12
Advanced	2	19	2	15	2	24
Specjalized	3	11	3	30	3	14
Weighted arithmetic mean	1,62		2,5		2,04	

Table 21 contains the summary results of the analyzes collected in tables 6-20.

Table 21.

Summary results of the analyzes collected in tables 6-20

Management method by:	Employee qualifications and skills desired in the era of Industry 4.0, and developed thanks to the use of the method	Self-assessment of specialists (employees of industrial enterprises) by generation		
		X	Y	Z
communicating	communication competences using instant messengers	1.84	2.1	2.9
	the ability to use and interact with computers and intelligent machines	2.1	1.9	1.5
	data protection and cybersecurity understanding/skills	1.1	1.5	1.4
Average rating		1.68	1.83	1.93
motivating	ability to adapt in the workplace and plan development in the context of digital transformation	1.62	2.5	1.24
	readiness for changes regarding digital transformation / involvement in the digital transformation process	1.46	1.54	2.6
	creativity in implementing increasingly better digital solutions	1.1	1.5	1.56
Average rating		1.47	1.83	1.8
delegation of authority and controlling	interdisciplinary and generic knowledge of technologies and know-how about machines necessary to operate them	2.5	2.76	148
	specialized and generic knowledge of factory operations and production processes	2.86	1.9	1.4
	ability to make decisions regarding digital transformations	1.1	1.5	1.36
Average rating		2.15	2.05	1.41
goals	ability to analyze and process data received from machines	1.62	2.5	2.24
	ability to enter visualization data and make decisions based on data	1.46	1.54	2.6
	generic knowledge of business statistics	1.1	1.5	1.2

Cont. table 21.

Average rating		1.39	1.85	2.06
building organizational culture	ability to adapt in the workplace and readiness for change	1.62	2.5	1.44
	ability to work in a team and willingness to share knowledge	1.44	2.5	1.4
	the ability to change the way of thinking under the influence of science	1.44	2.5	2.4
Average rating		1.5	2.5	1.62

Source: own study.

The tables shows the evaluation of employees' qualifications and skills across different generations in the context of Industry 4.0, divided into four key areas: communication, motivation, delegation of authority and control, and building organizational culture. Generation Z demonstrates higher skills in digitalization and readiness for change, while Generations X and Y place more emphasis on technical knowledge and teamwork skills.

Discussion

The human factor is a fundamental component shaping new digital supply chains (DSCs) (Garay-Rondero, Martinez-Flores, Smith, Caballero Morales, Aldrette-Malacara, 2020). Human interaction with 4.0 technology has become an essential driver of sustainable and resilient supply chains (Xu et al., 2021). The increasing demand for digitisation of supply chains is forcing a focus on humans and enhancing their digital competence (Stiffler, Watt, Chumakov, 2020). A systematic literature review confirmed that digital technologies implemented in supply chains require new capabilities and skills from human resources (Benesova et al., 2017). It has also been confirmed (following Sima et al., 2020; Pejic-Bach et al., 2020; Matt et al., 2020), that there are cultural differences between employees of different supply chain organisations and differences between staff belonging to different generations. These differences consist of disparities in the possession of digital competences, but also in the possession of so-called soft competences. Researchers who have highlighted the changing demographics of the workforce in the context of the challenges of Industry 4.0 (Calzavara et al., 2020; Javaid, Haleem, 2020) have suggested that 'there is generational diversity that needs to be taken into account when applying selected management approaches during the digital transformation of the enterprise and the entire supply chain'.

Other researchers have highlighted that the introduction of Industry 4.0 systems and technologies brings opportunities and pitfalls for organisations and management (Benesova, Tupa, 2017; Nahavandi, 2019; Xu et al., 2021). These researchers sought to affirm that 'a manager should apply utilitarian management methods and seek universal principles that will support him or her in managing a multicultural and multigenerational workforce during a difficult time of transition'. The recommendations formulated in the article were guided by the research (Nahavandi, 2019; Xu et al., 2021). The aforementioned authors believed that

existing management methods may no longer be acceptable in companies and supply chains implementing the new technologies of Industry 4.0 and 5.0. Following (Dezi et al., 2018; Ozdemir, 2018) it was confirmed that it is, however, possible to look for golden rules while applying utilitarian methods to manage multicultural and multigenerational human resources. Based on utilitarian management methods and identifying new competences of employees related to the support of Industry 4.0 (Wang, Kang, Childerhouse, Huo, 2018; Fantozzi, Di Luoizzo, Schiraldi, 2024; Khan, Kumar, Singh, and Ashraf, 2024; Zanon, Sigahi, Anholon, and Carpinetti 2024), own research was prepared and conducted. The research was conducted in companies in the automotive industry that had undertaken digitisation efforts for integration within their own supply chains. The research conducted confirmed that the introduction of Industry 4.0 systems and technologies entails opportunities and risks for organisations and management (Benesova, Tupa, 2017; Nahavandi, 2019; Xu et al., 2021). The research also confirmed that ‘a manager can, using known management methods and effectively compensate for identified competency gaps’. The inspiration for seeking recommendations for managers managing a multicultural and multigenerational workforce in the automotive supply chain was the literature cited in the chapter: Literature review. Confirmation of the hypotheses and recommendations are included in the chapter: Conclusions.

Conclusions

Multigenerational workforce management methods are evolving in the era of the fourth industrial revolution. The dynamics of change in companies and supply chains undergoing digital transformation, and the challenges of managing human resources, call for new management methods. Inspired by the literature reviewed and bearing in mind that the multi-generational workforce of cooperating companies represents unique values, preferences, needs and digital competencies, the following recommendations were made:

- Managers of digitised supply chains (in which their companies co-operate) should note the cultural and generational differences of the workforce.
- When working with a multicultural workforce within a single supply chain, managers should strive to select and apply a guiding management method (in the era of Industry 4.0 for companies in automotive supply chains, the most important method to be applied among professionals - will be: management by objectives).
- When working with a multi-generational workforce, the manager must be very flexible in applying subordinate management methods. The methods known so far should be modified for each generation. It is therefore worth considering introducing complete freedom in their selection and application.

- When applying the management-by-communication method, one utilitarian principle applies, i.e. providing quick feedback. The key is an efficient flow of communication within the company, based on the concept of rapid feedback. However, it is worth paying attention to the preparation of the different communicators preferred by the three generations described. It is also worth paying attention to the intonation of messages and the words and phrases used, which should be adapted to the generation. Preparing guidelines for differentiating communicators and messages would improve the atmosphere in a digitised workplace. It is certainly necessary to create a space for friendly relations between multigenerational employees (so that they can support each other in the difficult transition process).
- When applying the management by delegation method, it is worth using the universal principle that tasks should always be delegated. Only select the difficulty of tasks according to the experience, skills and qualifications of the employees. What is important is that people have the power to do things, to make decisions, and are able to demonstrate and perhaps even self-actualise. By delegating increasingly challenging tasks, the manager will certainly have a positive impact on the employee's perception of importance, belonging and loyalty. Different generations require different clarification of delegated tasks. Generation Z is the most demanding in this respect.
- When applying the management-by-motivation method, it seems to be a universal principle that a manager should create the conditions for the continuous professional development of employees. However, Generation Z will play a key role in the digital transformation, having the least experience but the highest digital competence. The most effective form of motivating generation Z seems to be the implementation of gamification. Other generations may not accept this form and their motivation should take traditional forms, such as appointing X and Y to friendly transformation teams where they will be recognised for their experience.
- When applying the management-by-controlling method, it is worth considering building control into daily activities and processes (developing a transparent control and evaluation system). Generation Z lacks mental and emotional stability and personalised controls could increase insecurity and be a catalyst for stress. Older generations will also view systemic solutions positively. In the age of digitalised processes, constant control of work is possible and is likely to have a positive impact on the wellbeing and effective performance of all generations. If it is necessary to give an employee a low appraisal, the manager should be able to convey a non-intrusive critical message. This is important in the case of generation Z, which is very sensitive to any unfavourable and uncomfortable situations and prone to feeling negative emotions.

- Using the management-by-objectives method, an ironclad principle can be reapplied - even in a multi-generational working environment. Everyone should be involved in building goals, starting with operational goals (lower-level employees should be involved in formulating them) and ending with strategic goals (built with senior employees). It is important to remember that all generations are in agreement about being able to express their own thoughts and suggestions based on their position. The manager should listen carefully and, if possible, link the goals of the employees to those of the company and the supply chain. For Generation Z in particular, it is important that their career path coincides with the technological developments of the organisation and the super-organisation. When working with Generation Z, care should be taken not to belittle their skills and to try to break down the barrier that may arise from a lack of confidence in their experience and competence.
- Adapting the company culture to that of the supply chain is very difficult for the manager. The manager has to keep in mind that any change in organisational practices will be interpreted differently by generations shaped by a different socio-cultural reality. The most important thing in the difficult process of building a new organisational culture is for the manager to be willing to understand the motives of each generation and to be understanding of the differences and values. The most valuable attribute of any organisational culture being built is mutual intergenerational respect and inclusivity. In a challenging time of digital transformation, these attributes will be helpful in bridging the competency gaps of multigenerational team members.

The analysis of the literature confirmed that modern management in a multicultural and multigenerational work environment poses numerous challenges for managers, but also opens up new opportunities. The key to success is to skilfully exploit diversity by adapting methods of motivation, control, goal-setting and building the organisational culture of the supply chain.

The results of the research confirm that managing people from different cultures and generations can present both opportunities and challenges due to different needs in terms of: communication; motivation; delegation and control; goal setting; and values, which determine the construction of the organisational culture. Managers should create a space for professional development in which employees from all co-operating organisations and all generations can excel and realise their aspirations. Particular attention should be paid to generation Z, who, although they may lack experience, have high digital competence, which is crucial in this age of technological transformation. There are several recommendations from the research for effectively managing employees from different cultures and generations:

- Recognise that each generation has unique experiences, values and communication preferences shaped by the events of their growing up years.
- Familiarise yourself with the characteristics of the generations remaining in the labour market, such as Generation X, Generation Y and Generation Z.

- Adapt the method of management through communication to their preferences for communication channels and style of message.
- If your company is undergoing a digital transformation, know that Generation Z is best equipped to communicate using Industry 4.0 tools (the average score for a Generation Z professional coming from an automotive company is 1.93 points out of 3 possible - see Table 19). However, delving deeper into the assessment criteria used in the survey, it is important to note that Generation Y scores better in the self-assessment of 'ability to use and interact with computers and intelligent machines'. - When delegating authority, duties and responsibilities, consider that each generation has different experience, seniority and knowledge.
- If your company is undergoing a digital transformation, know that generation X is best placed to delegate authority to make important transformational decisions. This is because they highly value their 'specialist and general knowledge of factory operations and processes'. Therefore, X should be on the decision-making team. Delegate important tasks/decisions to Y because, they rate themselves highly for their 'interdisciplinary and general knowledge of the technology and know-how of the machines needed to operate them' and their 'ability to make digital transformation decisions'. The self-assessment shows that Z are not yet ready to delegate difficult transformation decisions to them.
- Use the management-by-motivation method. It seems to be a universal principle to recognise achievements and create an environment that enables continuous professional development for employees.
- If your company is undergoing a digital transformation, know that Generation Y professionals adapt best in the workplace and identify with the planned digital development. Generation Z is rated highest for: 'readiness for change regarding digital transformation / commitment to the digital transformation process' and "creativity in implementing better and better digital solutions".
- When managing targets, distribute them, taking into account the experience and knowledge that older generations bring, and create opportunities for knowledge sharing and mentoring. From interviews (with automotive managers), the Management by Objectives method (used among executives and specialists) is leading the way in transforming automotive supply chains.
- Formulate measurable goals, clearly articulate objectives and provide regular feedback on the evaluation of goal achievement.
- Remember that it is your job (until AI replaces you) to set goals for individual employees. Make your job easier and manage your staff effectively by collecting and analysing data. Data on employee performance, satisfaction or motivation will allow you to make more informed personnel decisions. The use of analytical tools supports

the identification of areas for improvement and optimises the allocation of human resources. - If your company is undergoing a digital transformation, know that Generation Z professionals are best rated for their 'ability to input data, visualise and make decisions based on data', Y have the best 'ability to analyse and process data received from machines' and 'general knowledge of business statistics'.

- Promote a culture of continuous learning to attract the attention of younger generations who may value professional development opportunities. Be open to flexible working arrangements, being aware that younger generations may value work-life balance and flexible schedules. Allow for a variety of working styles, as some may prefer a collaborative environment, while others may excel in a more independent setting. Promote intergenerational integration. Encourage an inclusive environment where all team members feel valued, regardless of age. Avoid creating assumptions and stereotypes based on age. Treat individuals as unique contributors with different skills and perspectives. Encourage collaboration and inclusion in decision-making processes. Ask for feedback from different age groups to ensure different perspectives are taken into account when making important decisions. Emphasise a common supply chain goal. Connect the inter-organisational team through a common purpose or mission that transcends generational differences. Help individuals see how their unique contributions contribute to the overall success of the team or organisation. By acknowledging and accepting the differences between team members, you can create a more inclusive and collaborative work environment that leverages the strengths of each generation.
- If your business is undergoing a digital transformation, know that Generation Y professionals are the most adaptable in the workplace and are ready for change; they will bridge the gap between the digitally conventional X experience and the digitally creative but uncertain Generation Z.

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AN INTERNATIONAL THEATRE FESTIVAL AND CITY BRANDING: INSIGHTS FROM MANAGERS REPRESENTING FOREIGN ARTISTIC TROUPS

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Purpose: This article aims to identify the role of an international theatre festival in city branding by analyzing the perspective of participants representing foreign artistic ensembles.

Design/methodology/approach: The study is based on a qualitative case study methodology, focusing on the Direction East Theatre Festival in Białystok. Six in-depth individual interviews (IDIs) were conducted with theatre managers from Eastern Europe and analyzed using MAXQDA software and an abductive approach.

Findings: Participation in the festival transforms the perception of the city from initial unawareness or stereotypes to a positive, detailed image. Discovering Białystok's multicultural roots generates strong identity connections, redefining "the East" as a strategic asset. The festival's high organizational professionalism (systematic approach, team commitment) is crucial for the city's brand credibility. The mechanism of the "ambassadorial effect" was also confirmed, where high-quality experiences lead to spontaneous promotion of the city by participants.

Research limitations/implications: Limitations include the subjective nature of the data and the inability to generalize findings to a broader population due to the small, purposive sample. Longitudinal studies, inclusion of a wider range of stakeholders, and comparative analyses with other festivals are recommended.

Practical implications: Recommendations include investing in organizational professionalism, fostering an engaging atmosphere, involving the audience, developing international cooperation, consciously strengthening the ambassadorial effect, professional visual (including linguistic) communication, and integrating events with urban space.

Social implications: The festival fosters intercultural dialogue and strengthens inclusive local identities, positioning the city as open and cosmopolitan.

Originality/value: The article makes a significant contribution to place branding theory by exploring the under-researched area of theatre festivals from the unique perspective of international artists in the specific geopolitical context of Białystok. It presents a three-phase model of perception change, enriching existing theoretical frameworks.

Keywords: Place branding, City branding, Theatre festival, Experience marketing, Multiculturalism.

Category of the paper: Case study, Research article.

1. Introduction

The application of branding concepts in urban management has become a subject of growing interest among both scholars and practitioners (Stevens et al., 2021). Increasingly, brands are being perceived as integral elements of public space, and local governments are beginning to recognize their strategic importance (Rudolf, Glińska, 2019).

Braun and Zenker (2017) define place branding as the overall image and set of associations (both functional and non-functional) related to a given location, based on its visual, verbal, and behavioral expressions, which are reflected in the city's objectives, communication, values, and stakeholder culture. A brand refers to the identity established for a specific territory with the aim of promoting its uniqueness. This identity is grounded in the distinctive and unique features of a place (Ginesta et al., 2024). Kalandides (2012) emphasizes the need for co-creation of place identity by a variety of stakeholders, including residents, local authorities, entrepreneurs, and tourists. The dynamic and relational nature of place identity forms the foundation for building its brand (Kavaratzis, Hatch, 2013). The goal of brand management is to shape specific associations with a given place among targeted audiences (Reynolds et al., 2022). Municipal governments engage in branding initiatives aimed at stimulating economic development, attracting talent, and encouraging visits to the city (González et al., 2025). A positive city brand image plays a crucial role in attracting investors, tourists, employees, students, and prospective residents, and is essential in urban management processes (Grębosz-Krawczyk, Zakrzewska-Bielawska, 2024).

Culture plays a particularly significant role in defining a city's brand identity, understood as the activity of municipal cultural institutions, whose influence often extends beyond the city's administrative boundaries (Rudolf, Glińska, 2019). In the place marketing literature, there is growing interest in the role of artistic festivals as tools for supporting city branding (Getz, 2008; Quinn, 2010; Johansson, Kociatkiewicz, 2011). Theatre festivals, however, are less frequently examined compared to other types of events in place branding research. Nevertheless, they can serve as a valuable tool for brand development. Their significance lies in the creation of deep, culturally rooted community narratives that can enhance a city's recognition and identity at both national and international levels (Wilmer, Koski, 2018; Oham, Ejike, 2022; Thomasson, 2022).

The aim of this article is to identify the role of an international theatre festival in building a city's brand from the perspective of participants representing foreign artistic ensembles. The study employs a case study methodology, focusing on the „Direction East” theatre festival organized in the city of Białystok. As part of the case analysis, in-depth interviews were conducted with theatre group managers from several European countries. The study's conclusions may be converted into managerial implications, targeting managers of cultural institutions and representatives from Local Government Units responsible for the oversight of cultural institutions.

2. Literature review

The Development of City Branding

In marketing terms, a city can be perceived as a product—a combination of tangible attributes and intangible components that interpenetrate to create a unique experiential space for residents and other categories of "users" of the city's offerings (Glińska et al., 2009). The need to treat the city as a multidimensional product, whose brand is shaped by the experiences of both residents and visitors, is also emphasized by Kavaratzis and Ashworth (2005). As a distinct type of product, the city competes with other urban centers for factors that ensure a high quality of life for its inhabitants. It vies for the attention and trust of various stakeholder groups: investors, tourists, students, skilled workers, as well as media interest and the engagement of the local community (Florek, 2013), which constitutes the basis for brand development.

The concept of city branding emerged in the late 1990s, when Anholt (1998) introduced the notion of "nation branding", later adapted to the urban context. In his subsequent work, Anholt (2006, 2010) developed the theory of "competitive identity", which goes beyond traditional approaches to place marketing by emphasizing the importance of a coherent strategy integrating the place's politics, economy, and culture. According to Dinnie (2011), city branding has evolved from mere place promotion to comprehensive identity management.

Gilboa et al. (2015) emphasize that by integrating branding techniques into governance, city authorities can unify stakeholders around a new competitive identity, subsequently communicated to target audiences. In the domain of territorial branding, a key responsibility of brand managers is to communicate selected attributes of the city. These efforts result in perceptions based largely on psychological and emotional associations with the place (Braun et al., 2012). Cities seek to utilize both material and immaterial elements of their identity to create messages that appeal to a broad audience (Rudolf et al., 2023).

Branding thus becomes an increasingly widespread practice of "selling" specific characteristics of a city—its history, lifestyle, and culture—in order to gain new opportunities, prestige, or competitive strength (Zhang, Zhao, 2009).

Culture and Cultural Events in City Branding

The role of culture and cultural assets in shaping a city's identity is highlighted by numerous scholars, including Zenker (2009), Merrilees et al. (2012), Gilboa et al. (2015), Glińska (2016), and Rudolf & Glińska (2019). Their research points to the significant contribution of a city's cultural offer to its brand, identifying key elements such as vibrant cultural institutions, the organization of events and festivals, live performances, and a wide range of opportunities to engage with culture in one's free time (Rudolf, Glińska, 2019).

In examining the cultural dimensions of city branding, it is worth referencing the work of Richards and Palmer (2010), who analyzed how cultural events transform urban space and influence its perception. Ashworth and Kavaratzis (2015) explored the use of cultural heritage in city branding, while Govers (2018) examined the role of the creative sector in developing a competitive urban identity.

Several researchers have focused specifically on the role of cultural events in city branding. Richards (2017) investigated how such events impact brand value by generating unique experiences. His findings suggest that the success of cultural events depends on their authenticity and ability to engage diverse stakeholder groups. He also emphasized that events should be grounded in the local cultural context in order to produce distinctive experiences that resonate with both residents and visitors. Kavaratzis and Kalandides (2015) explored how cultural experiences are transformed into brand associations, proposing a participatory model of place branding in which cultural events—such as theatre festivals—serve as key tools for brand building.

Artistic Festivals in City Branding

In place marketing literature, there is growing interest in the role of artistic festivals as instruments for city brand development. Quinn (2010) emphasizes that festivals serve not only as tourist attractions but also as influential factors in shaping urban image. Her research highlights the long-term impact of festivals on urban development and their capacity to foster cultural tourism. She draws particular attention to the connection between festivals, local cultural identity, and urban policy.

Getz (2008), meanwhile, proposed a theoretical framework for analyzing events as strategic tools in destination management. He defined "event tourism" as a deliberately designed activity aimed at promoting cities through events, which can enhance brand recognition and shape visitor experiences.

Further insights are offered by Johansson and Kociatkiewicz (2011), who examined festivals as tools for repositioning Scandinavian cities on the international cultural map. They highlighted the tensions between creativity and control in event management, noting that festivals—beyond their artistic value—play a strategic role in territorial marketing. These studies portray artistic festivals not merely as temporary attractions but as complex instruments of urban policy, place branding, and local community engagement.

Theatre Festivals and City Brand Building

While considerable attention has been paid in the literature on place branding and event marketing to music, film, and multi-genre festivals, theatre festivals remain a relatively underexplored area. Their distinctive nature—rooted in performativity, local narratives, and cultural dialogue—positions them as especially valuable in the context of city branding.

Wilmer and Koski (2018) argue that international theatre festivals act as platforms for intercultural dialogue, where theatre becomes a medium connecting diverse cultural traditions and languages. They explore how such festivals can help position cities as open and cosmopolitan, which is especially valuable in attracting cultural tourists and investors. Similar conclusions were drawn by Hauptfleisch et al. (2007), who, studying South African theatre festivals, emphasized the role of theatre as a community-building tool in culturally diverse societies.

Bennett and Woodward (2014) offer an insightful perspective on how festival participation shapes a sense of belonging, particularly among individuals from different cultural backgrounds. Their findings are especially relevant in the context of multicultural and borderland cities, where theatre festivals may function as integrative forces that strengthen inclusive local identities.

Some scholars have investigated the relationship between theatre festivals and city brand development. Jakob (2012) approached this issue through the lens of “eventification”—the transformation of urban space into a stage for experience consumption. He noted that contemporary urban development increasingly prioritizes the creation and promotion of experiences. Theatre festivals exemplify this trend, turning both products and places into a kind of “theatre” in both literal and metaphorical senses. Eventification, in turn, is employed as a branding tool—festivals not only offer intense experiences but also contribute to constructing the image of a city as dynamic, creative, and attractive for living, working, and investing.

Oham and Ejike (2022) identified the evolution of branding strategies within the performing arts sector, emphasizing the role of events (including theatre) in shaping the image of institutions and cities. They stressed the importance of consistent visual communication, cultural values, and audience experience in creating a recognizable and authentic place brand through festivals.

Thomasson (2022), on the other hand, examined how theatre festivals in Edinburgh and Adelaide became central to city branding strategies, crafting images of dynamic, open, and culturally engaged urban centers. Her research also explored how the process of “festivalization” affects public space and urban identity, revealing tensions between promotional goals and the social and political dimensions of festivals.

3. Research Methodology

The research methodology was based on a qualitative approach. The primary research method was a case study analysis, which is understood as “an empirical inquiry that investigates a contemporary phenomenon within its real-world context, especially when the boundaries between phenomenon and context are not clearly evident” (Yin, 2003).

Achieving the article's objective was made possible through the selection and analysis of a case: the Direction East theatre festival, organized by the Aleksander Węgierko Drama Theatre in Białystok. This event was established in 2017, referencing the international idea of the Eastern Partnership - a cooperation program within the European Neighbourhood Policy involving six Eastern European countries: Belarus, Ukraine, Moldova, Georgia, Armenia, and Azerbaijan. The main goal of organizing the festival was to strengthen cultural cooperation between the Drama Theatre and institutions from the Eastern Partnership countries and cultural centers located in border regions. One of the organizers' aims was also to expand the cultural offerings in an area distant from Poland's largest cultural centers, namely Białystok - the capital of Podlaskie Voivodeship. The event is financed by the Ministry of Culture and National Heritage, the budget of Podlaskie Voivodeship, and the institution's own funds. Over eight editions, artists from Armenia, Belarus, Czech Republic, Georgia, Lithuania, North Macedonia, Ukraine, the United States, as well as Polish theatres from Tarnów, Bielsko-Biała, and Rzeszów, among others, have performed in Białystok.

"Direction East" is one of the few theatre events in Białystok that allows for the experience of intercultural relations and cooperation. The festival takes place annually and enables audiences to watch theatre performances by international theatres and groups. The strengths of the festival include: expanding the city's cultural offerings, the presence of guests from culturally diverse countries in Białystok, their grassroots promotion of the city, and the development opportunities for international cooperation in the field of culture, which constitute a potential that can become an element of the city's branding strategy.

Before commencing the research, the following research questions were formulated:

- RQ1.** How has participation in the international Direction East theatre festival influenced the perception of Białystok's city brand by foreign participants?
- RQ2.** How did foreign participants evaluate the Direction East theatre festival and its connections to Białystok's city identity?
- RQ3.** What benefits can Białystok's city brand gain from organizing the Direction East theatre festival, in the opinion of foreign participants?

To obtain answers to the research questions within the framework of the case study analysis, individual in-depth interviews (IDIs) were conducted. This is a commonly used technique in qualitative research. It is based on a natural human communication scheme - they resemble everyday conversations during which participants engage in dialogue, exchanging thoughts, formulating questions, and providing answers. An in-depth interview is a focused conversation between two people: the researcher and the interviewee, which can be structured and standardized in various ways (Glinka, Czakon, 2021). Such a conversation can take place as a direct face-to-face meeting or using communicators such as Zoom, Google Meet, MS Teams, FaceTime, and many others (Lobe, Morgan, Hoffman, 2020).

For a fuller picture of the studied phenomenon, "face-to-face" communication is more often used in scientific projects. In addition to the information contained in spoken words, this form allows for better reception of non-verbal cues (Onwugebuzie, Leech, Collins, 2010). Due to geographical distance and factors limiting mobility (e.g., the war in Ukraine, COVID-19), researchers now equally often use electronic communication means that also enable video connection. Compared to live conversations, online interviews have some limitations, but they allow for international research reach, flexibility, and acceleration of the research process (Glinka, Czakon, 2021).

The selection of an adequate research method determines the quality and reliability of the results obtained (Creswell, Creswell, 2018). IDI is a special type of interaction in which the researcher asks questions about opinions, experiences, objections, dreams, fears, and hopes, and the respondent provides answers to these questions (Knott et al., 2022). An in-depth interview, as a qualitative method, allows for a deep understanding of complex socio-cultural phenomena through the exploration of individual experiences and perspectives of the subjects (Kvale, Brinkmann, 2009). Research on the impact of cultural events on a city's image requires understanding the multidimensional relationships between various stakeholders (Richards, Palmer, 2010).

A particularly important factor justifying the choice of the IDI method was the international nature of the studied group. As Marschan-Piekkari and Welch (2004) note, international research requires particular sensitivity to cultural and linguistic context, which the applied method enables. In research on the perspective and experiences of theatre festival participants, qualitative methods are valuable for studying the intangible, emotional, and symbolic aspects of cultural events (Getz, 2010). Johansson and Kociatkiewicz (2011) successfully used in-depth interviews with artistic directors, obtaining valuable data on the processes of constructing narratives about a city through cultural events.

In summary, the choice of the in-depth interview stems from the characteristics of the studied group and the specificity of the research topic, enabling the acquisition of in-depth data on the perspective of participants of the "Direction East" Theatre Festival, representing artistic ensembles from Eastern Europe, which is crucial for understanding the festival's role in the city branding process.

The selection of respondents for the IDIs was carried out based on the list of participants from all editions of the "Direction East" Festival. Six individuals holding managerial positions in theatres from Eastern European countries, who visited Białystok as part of their festival participation, were selected.

Purposive sampling was used, which allowed for the selection of respondents possessing specific knowledge relevant to the adopted research objective (Patton, 2015). The sample included 6 respondents representing theatres from Armenia, Ukraine, Lithuania, North Macedonia, and Georgia, diverse in terms of culture, institution size, and artistic profile (Table 1). The institutions included national theatres, academic theatres, as well as non-

institutional theatres. The criterion for selecting respondents was their active decision-making role in the theatre's participation in the festival and their experience in institution management. This sampling approach enabled obtaining data from individuals possessing both decision-making competencies and a strategic perspective necessary to evaluate the festival's impact on the international perception of the city (Robinson, 2014).

Table 1.

Characteristics of respondents by organization, occupation, country and city

Symbol	Organization	Occupation	Country	City
R1	National Theatre Bitola	Theatre manager	Northern Macedonia	Bitola
R2	Movement Theatre	Theatre manager	Georgia	Tibilisi
R3	Alytaus Miesto Teatras	Theatre manager	Lithuania	Alytus
R4	Left Bank Theater	Theatre manager/director	Ukraine	Kyiv
R5	National Academic Gabriel Sundukyan's Theatre	Theatre manager/director	Armenia	Yerevan
R6	Vazha-Pshavela State Drama Theatre	Theatre manager	Georgia	Telavi

The study employed a **semi-structured in-depth interview**, which combines a structured set of questions with the flexibility to explore unplanned topics (Longhurst, 2003). This type of interview allowed for thematic consistency while adapting to the individual course of the conversation and the specificity of the respondent's experiences, which is particularly crucial in this type of research (Galletta, Cross, 2013). The interview protocol included 11 main (open-ended) questions, grouped into four complementary thematic areas, forming a logical sequence from individual experiences to strategic reflections, and consisted of the following parts:

- city perception - an area exploring respondents' initial perceptions of the city and their evolution in the context of festival participation, in line with the concept of place image formation through direct experience (Zenker, Braun, 2017);
- festival experiences - a block of questions concerning the multidimensional experience of festival participation, including organizational aspects, the event's atmosphere, accompanying activities, as well as a comparison with other events of this type and the emotional dimension of the experience. This section is based on the festival experience model proposed by Getz and Page (2016);
- festival's impact on city brand - an area analyzing the perceived benefits for the city resulting from the festival's organization, behavioral intentions (propensity for repeat visits), and evaluation of marketing activities, referencing the concept of place brand equity as per Jacobsen (2012);
- conclusions and recommendations - a section covering suggestions for optimizing festival organization, reflections on the event's connections to the city's identity, and an open question allowing respondents to raise important issues not covered in previous questions.

The structure of the interview protocol was designed according to the "funnel sequence" principle, starting with general questions and gradually moving to more specific and reflective ones (Morgan et al., 2008). Questions were formulated in an open-ended, non-judgmental manner, avoiding specialized terminology, with the aim of minimizing communication barriers in an intercultural context (Ryen, 2002).

Due to geographical location and the geopolitical situation in some of the surveyed countries, it was decided to conduct all interviews remotely, via the MS Teams platform, which allowed for video recording of the interview after obtaining informed consent from the respondents. Interviews were conducted between February and April 2024, each lasting from 45 to 60 minutes. This strategy allowed for adapting the research process to the time and logistical capabilities of the respondents (King, Horrocks, 2010). Subsequently, textual transcripts of the recordings were made using Turboscribe software and exported as .docx files. In the next step, the accuracy of the automatic transcription process was checked, necessary corrections were made, and the text was formatted for better readability. The transcription process was carried out using standards of denaturalized transcription, which preserves the content of utterances while correcting pauses, repetitions, and paralinguistic elements that do not add substantive value (Oliver et al., 2005). The interviews were conducted in English and then translated into Polish.

Data analysis was performed using MAXQDA software, which enabled systematic coding, categorization, and interpretation of the collected textual materials (Kuckartz, 2014). A multi-stage qualitative coding process was carried out: (1) initial familiarization with the material and marking key fragments, (2) creating codes based on identified patterns and significant statements, and (3) organizing codes into a hierarchical structure reflecting the main thematic areas of the study (Schreier, 2012). In the elaboration of the results, an abductive approach was used, combining elements of inductive and deductive analysis, which allowed for the identification of both themes emerging directly from empirical data and those related to existing theoretical frameworks of place branding (Timmermans, Tavory, 2012).

The analysis of the collected material was conducted in accordance with the adopted principles of qualitative coding in MAXQDA software. The identification of 14 main thematic categories allowed for a systematic examination of the multidimensional impact of the international "Direction East" theatre festival on the city's brand from the perspective of international participants. The abductive approach used enabled the combination of empirical observations with existing theoretical frameworks of place branding (Timmermans, Tavory, 2012), resulting in an in-depth analysis of place perception formation processes.

4. Results

Regarding the search for answers to RQ1 "How has participation in the international Direction East theatre festival influenced the perception of Białystok's city brand by foreign participants?", the analysis of empirical material obtained from the interviews revealed a distinct three-phase process of experiencing the city: the pre-festival phase, re-evaluation of the image during the festival, and a positive post-festival transformation. The pre-festival phase was characterized by a predominant lack of knowledge about the city or its perception as a secondary cultural center. Statements from respondents from various countries (North Macedonia, Armenia, Georgia, Lithuania, and Ukraine) confirm that Białystok, prior to their visit, did not function in their awareness as a significant point on Poland's cultural map, with the exception of a respondent from Lithuania, who knew the city due to its theatre traditions and geographical proximity. One respondent [R1] openly admitted to a lack of knowledge: "We didn't know too much about Białystok and we just based it on our general idea and knowledge about Poland as a country". Similarly, a manager from another theatre [R5] stated: "When we talk about Poland, Białystok is not the first thing that comes to your mind". The head of another theatre group [R2] expressed expectations: "I expected a small European city, with a lot of space". Particularly interesting was the statement of a Ukrainian director [R4], who had a specific attitude in the context of the war: "I didn't know about Białystok. And it was my first time meeting the city. And we had a topic about a full invasion, about people abroad, about women abroad. So I wasn't and didn't feel like a tourist". One individual [R6] noted: "I've been to many other cities in Poland before, traveling, studying, and also visiting them, as well as for business purposes. But I knew that Białystok would be absolutely different". The analysis of Białystok's pre-festival perception perfectly illustrates the "departure zone" of a place experience in the framework of Pine and Gilmore's (1998) theory, where a lack of familiarity or stereotypical notions precede the actual aesthetic and educational experience. According to this theory, a full place experience requires engaging all four dimensions (entertainment, educational, escapist, and aesthetic), which in the case of the surveyed respondents was only to occur in subsequent phases of their contact with Białystok.

The experiences of festival participants reveal a positive re-evaluation of initial perceptions of Białystok, focusing on three dimensions: discovering the city's multicultural history, appreciating the organizers' hospitality, and being delighted by the festival audience's engagement. This last element emerges as a key factor shaping the city's image. The director of one of the theatres [R1] described the discovery process in detail: "we visited almost the entire city center, it was a two-hour tour. We visited all the main landmarks and squares in Białystok". Particularly significant was the discovery of multicultural roots: "we heard a really interesting fact that in Białystok you can buy 'boza' (a slightly fermented drink from Balkan and Turkish cuisine), which we didn't know before, and it was especially interesting that it was brought by

Macedonian immigrants in the early 1920s". The same respondent [R1] added: "we went to the Jewish ghetto in Białystok and the guide told us everything that happened during World War II". Another participant [R2] enthusiastically reported: "we were excited, and we liked this city very much". He also appreciated the hospitality: "we had a great host (...) the hospitality at the festival was so good that we ate a lot of chocolate, we actually ate everything, and the chocolate was the best!" The director of another theatre [R3] positively assessed the local audience: "I was impressed with the audience. There were many people at both of our performances". Another surveyed person [R5] confirmed: "The organizers also prepared a very hospitable and warm welcome for us. And I could also see that the audience, the best part for me is how well prepared the audience was (...) I could feel how emotional these people are, how deep they are". Another respondent [R6] added: "the best part for me is how well prepared the audience was and they not only participated in our shows, and had interactions after the performances (...) this small city and this wonderful audience are actually very actively involved in the world of theatre. For me, it was a bit surprising". The theme of the festival audience repeatedly appeared in the statements, whose activity and engagement positively influenced the perception of both the city and the event: "I wouldn't say it's everywhere in the world, this kind of unique audience and unique perception of the artistic and creative world itself. People in Białystok truly love theatre (...) When I think of Białystok, the first thing that resonates in my mind with the city is the Direction East Festival" [R6].

Analyzing these experiences through the lens of place brand equity (Konecnik, Gartner, 2007), it can be observed how, during the festival, all dimensions of Białystok's brand value are strengthened: from brand awareness (recognition of the city as a cultural center), through perceived quality (level of festival organization) and positive associations (hospitality, engaged audience), to brand loyalty (expressed through the desire to return and sentiment towards memories).

The post-festival perception of the city was unequivocally positive for all respondents. One participant [R5] showed the clearest transformation: "after visiting the Direction East festival, I think that when we talk about Poland, the first thing that comes to my mind is Białystok". Another participant [R6] noted: "after participating in the festival, we checked every subsequent year whether it was just our emotional connection or if we all actually had this objective attitude." The importance of the festival for future international cooperation was often emphasized: "this is the beginning of a very beautiful and nice cooperation between two theatres (...) the day after the festival ended, we had an invitation for the next edition". Similarly for the Lithuanian theatre: "We have common plans. We are very much looking forward to going there (...) we are doing our joint project. And we will have five days" [R3]. Recommendations for other theatres to participate in the festival also appeared: "you should definitely go there and see the festival, they will choose you, it's a very good opportunity to go and see Białystok, and the people are very nice, and the festival is very good, very well organized" [R2]. The human factor was of greatest importance for one respondent [R4]: "maybe

it's a bit funny, but I would say that the face of the city for me, for Białystok, is the face of the festival organizer”.

The unequivocally positive perception of Białystok through the experience of participating in the Direction East Festival confirms Zenker and Braun's (2017) concept of the strategic role of cultural events in city branding. Analyzing respondents' statements in search of answers to RQ2. "How did foreign participants evaluate the Direction East theatre festival and its connections to Białystok's city identity?" several aspects were considered: impressions of the city, atmosphere and emotions, festival organization - constituting the foundation of a positive experience. Promotional activities, accompanying events, and comparisons with other festivals were also included. The "Organization" category was a key element in evaluating the festival from the participant's perspective, significantly influencing the city's image. One manager [R3] emphasized the importance of organizational continuity: "the people who work on the festival, they literally work on the next edition from the first day the last edition of the festival ended. Actually, the day after the festival ended, we had an invitation for the next edition." She then added: "We go to Białystok and we know that everyone will be very helpful, everything will be fine, very well prepared". The head of one of the ensembles [R2] particularly valued the professionalism of the technical staff: "the stage technical crew was so good that when we started preparing the lighting, they did it in one second (...) we finished our rehearsal before the performance because everything was ready". A representative of another theatre [R5] noted the systematic nature of the actions: "I could see that the main people, the main players in the organizing team are very dedicated to this work. Very dedicated". Others also highly praised the organizers' approach: "the organization was on a high level and this is very important for me, because we also organize a new directing festival in my theatre (...) I come to festivals not only as a participant, but as a colleague who organizes a festival. That's why I think it's a really high level when you are surrounded by this attention all the time" [R4]. Organizational flexibility was also appreciated: "the organizing team of Direction East Festival also did a great job when they were working on bringing the Direction East Festivals to an online version during COVID-19. We also participated in that edition of the festival (...) you know how artistic people were hungry for these kind of opportunities at that time" [R6].

While the organization of the Direction East festival generally received positive feedback, respondents identified key areas for improvement, namely networking, critical engagement, and overall festival visibility and promotion. A recurring desire was for a more integrated festival experience beyond just performances. One respondent wished for "more things that are around the festival, but not a performance... something that will bring all people closer. I also understand that this is a really big budget issue" [R1]. This highlights a need for informal gathering spaces to foster connections. Another manager added, "I know that this is a common question about budgets, about money. But of course, I would prefer to come earlier, leave later and have this networking part" [R4]. The lack of dedicated networking, including a "festival club" [R3], was a missed opportunity for dialogue. Furthermore, critical reception and

documentation require development. A manager suggested "critics... who could speak and write more about the performances" [R1], indicating a gap that could enhance the festival's professional image. Practical issues included poor urban visibility. One participant noted, "When you come to the Direction East festival, you don't see any signs in the city" [R3]. Communication barriers also arose: "I was badly translated... conversations with the audience are sometimes even more important for us" [R4]. This points to the need for high-quality translation. Finally, program diversification was suggested to broaden appeal, such as "proposals for a younger audience" [R3], which could increase reach. These critical insights, despite budget limitations, offer valuable recommendations for enhancing future festival editions.

Such high organizational quality not only affected the comfort of participants but also, in line with Richards and Wilson (2004), strengthened the positive image of the city as a place open to culture, capable of professionally implementing international events. The statements of Direction East festival participants show diverse opinions on promotional activities - on one hand, the high quality of visual materials and social media activity were praised, while on the other, insufficient visibility of the event in urban space was pointed out. The quality of visual documentation was appreciated, confirmed by the words of the director of one of the theatres [R3]: "you have a very good photographer, really. Especially after our first performance, which was a couple of years ago. We even asked if we could use those pictures for our theatre". Another director [R1] shared this opinion: "I like short films before performances and presenting some people from the crew of each performance, and also trailers of performances". He also noted the evolution of the marketing strategy: "I think the festival has good marketing. Maybe the first edition wasn't so 'aggressive', but the next two years were really active and nice, good marketing, especially on social media".

Despite the positive reception of marketing activities, participants also expressed criticism. One respondent [R3] noted the lack of event signage in urban space: "speaking about the festival marketing, I can make some remarks (...) when you come to the Direction East festival, you don't see any signs in the city". Greater activity in online communication was also postulated: "I think it would be useful to have some online streaming from the talks. That could encourage other people from Białystok and the audience to come" [R4].

The analysis of the "Marketing" category reveals that despite the growing professionalization of promotional activities, place branding - as per Anholt (2006) - remains a complex process that requires consistent management of the city's image, its cultural offerings, and its presence in public and digital spaces.

Unique character compared to other festivals

Comparisons of the Direction East festival to other cultural events in the region allow for grasping its specificity against diverse socio-political and organizational contexts. One participant [R1] contrasted it with their national situation: "in our country all festivals are

very weak in every aspect, and especially budgets. We cannot afford many side programs of organizing festivals". A representative from another theatre [R5] emphasized the unique hospitality: "what makes Białystok Festival different, it seems that the festival is the main mission of the whole group, of the whole theatre (...) the organizers were really doing everything to make the hosts feel really comfortable". Another participant [R4] considered the specificity of the wartime context: "every festival for us, in some ways, it's the same. Because it gives us the possibility of having a voice, of talking about war, of talking about Ukraine".

In line with Getz and Page's (2016) concept, the strength of a festival as a place-making tool lies in its ability to offer unique experiences - those that not only engage artists but also provide them with space for dialogue with the audience and real social impact.

Atmosphere as a meaning generator

The "Atmosphere" category was consistently described as unique, emotional, open, and conducive to building relationships among artists, audience, and organizers. One respondent [R2] recounted an extraordinary moment: "one Polish journalist stood up and said that I want to thank you and I want to sing a song for you (...) it was the first time in our life that somebody sang a song for us (...) it was so emotional". Another participant [R3] also appreciated the quality of interaction with the audience: "it's very good to have post-performance reflections, to have discussions - your festival enables this". One interviewee [R6] noted: "I would say that the overall atmosphere was so dynamic and interesting on many levels (...) I still cherish those days and the memories we had in Poland".

This festival transcends the sphere of a cultural event, becoming an engaging, multi-level experience that influences the identity of recipients and their perception of the host city, referencing Pine and Gilmore's (1998) concept of the experience economy.

City Identity in an International Context

Statements from foreign participants indicate strong connections between Białystok's city identity and the character of the event. The director of one of the theatres [R1] positively assessed the geographical connotations: "when I first thought about it, I understood why the name is 'Direction East' (...) it's a really nice thing, to see something that is really oriented towards Eastern European countries". Another manager [R5] saw the festival's name as a symbol of openness: "the city is open. It's an open society (...) Direction East is doing its best to invite something that is not national. This is also characteristic of Białystok". The international potential of the event was also emphasized: "The Direction East Festival could be an event that actually contributes to making Białystok an important cultural landmark" [R6].

A deeper analysis of the qualitative data reveals significant concerns regarding the festival's identity and its integration with the urban fabric. These critical voices point to the need for a more cohesive vision and a stronger connection with the host city. A fundamental question

about the festival's core purpose emerged from the discussions: "What are we actually talking about, what is Direction for all of us? Is it the same Direction? Is it the same vector? Are we just Direction as a geographical part, but not a part of meanings and a part of strategy, a cultural strategy for tomorrow?" [R4]. This suggests a perceived lack of a clear, shared vision or strategic direction for the festival beyond its geographical designation.

Moreover, managers expressed a desire for a more pervasive and engaging festival presence within the city itself. One suggestion was that "maybe these accompanying things and accompanying events of the festival could be spread throughout the city (...), so that festival guests have a broader or more specific picture of what is happening" [R1]. This indicates that the festival's current reach might be too limited, narrowing the immersive experience for international guests. This sentiment ties into a broader reflection on the relationship between festivals and their host cities: "Usually... there is often no connection between the city and the festival... Does the festival have to become educational in some sense?" [R4]. Concrete suggestions for strengthening this urban integration included: "Organizers could definitely think about an opening and closing ceremony. (...) Maybe also better visibility in the city. More posters, actions, activities, performative events in the city streets" [R3]. These highlight that the festival's limited public presence and lack of city-wide engagement activities diminish its overall impact.

These critical perspectives emphasize that for the Direction East festival to truly thrive and fulfill its potential, it may need to re-evaluate its core identity and actively seek ways to embed itself more deeply into the city's life and consciousness, moving beyond an event focused solely on a specific venue.

According to Kavaratzis and Ashworth (2015), urban branding is not a simple promotional activity but a complex process where meanings are created through experiences, relationships, and narratives - which is confirmed in the case of Białystok and the Direction East festival.

Emotional engagement as a catalyst for place attachment

The emotional category showed the intensity of foreign festival participants' experiences. One director [R5] described impressions from a post-performance discussion: "the lady in the audience who said such a compliment about our performance that in a way it was like electricity that passed through my body (...) it really, it emotionally broke me, all of it, all these events". The festival's diplomatic potential, a chance to improve relations between countries, was also pointed out: "we are all divided now. And I believe that the purpose of such festivals is just to give us one more chance to build this dialogue between countries and having this specific historical background between Ukraine and Poland now" [R4].

Cultural events not only provide artistic content but also create a framework for emotional and social interactions that give places meaning, aligning with Smith's (2012) concept of "meaning generators".

In interviews with respondents, they were also asked about potential benefits they believed the Białystok city brand could gain from organizing the Direction East theatre festival [RQ3]. It turned out that the International Direction East Theatre Festival is perceived by foreign participants as an initiative bringing multidimensional benefits to the host city. A representative from one of the theatres [R5] stated that "Direction East Festival makes Białystok a better place, for sure, especially in the theatre world (...) I would like to come back with my family". Another respondent [R2] observed a positive effect: "this trip to Poland had such an impact that (...) just because we played Hamlet at the festival in Białystok, in April we are going to Adana, Turkey". The conclusions lead to Anholt's (2006) concept, according to which cultural events serve as place branding tools, influencing its international recognition and attractiveness.

The analysis of Direction East festival participants' statements indicates the need to expand festival activities into Białystok's urban space. Postulated actions included: "organizers definitely could think about an opening and closing ceremony (...) some kind of parade in the main part of the city with artists invited from different countries" [R3]. Other respondents [R1] had similar conclusions: "maybe these accompanying things and accompanying events of the festival could be spread around the whole city, organize a concert in another part of the city (...) mark some places that are symbolic for the city". Attention was also drawn to the quality of translations: "really, really, really important for us to be heard" [R4]. Words of support also emerged: "don't stop. And I know that not stopping is very difficult (...) don't stop and don't lose the really friendly atmosphere that has already been created" [R5].

Despite difficulties with the renovation of the theatre building - the festival organizer - the value of continuing the festival's friendly atmosphere was emphasized. These recommendations correspond with Richards and Wilson's (2004) concept, according to which the integration of cultural events with urban space creates a multidimensional experience, building place identity. Such an approach increases the visibility of events and strengthens local community engagement. Implementing these strategies could enhance the festival's impact on Białystok's cultural landscape.

5. Discussion

The qualitative study conducted among representatives of foreign theatre ensembles participating in the "Direction East" festival revealed that this event plays a significant role in transforming the perception of the city of Białystok. Before arriving, many respondents had no information about the city or perceived it as marginal within Poland's cultural context. However, participation in the festival initiated a process of re-evaluation - all respondents transitioned from indifference or unawareness to a positive and detailed image of the city as

an open, professional, and culturally active center. The building of a positive city brand perception was influenced by three main elements:

- festival organization - participants unanimously emphasized the high organizational level of the event - systematic approach, attention to detail, technical competence, and team commitment. Both stationary activities and earlier online editions were positively evaluated, which aligns with Richards and Wilson's (2004) theory regarding the impact of event execution quality on the host city's image;
- festival atmosphere - described as friendly, open, dynamic, and conducive to building relationships. Meetings with the audience, post-performance discussions, and direct interactions played a particularly important role, which - in line with Pine and Gilmore's (1998) "experience economy" concept - create deep emotional connections with the place;
- emotions related to festival participation - the most frequently mentioned aspects were strong emotions related to the audience's reception of performances, spontaneous gestures (e.g., a Polish journalist singing), but also a sense of closeness with the organizers. These emotions constituted a long-lasting memory resource for participants, thus an element building loyalty towards the place brand (Konecnik, Gartner, 2007).

Both the festival's name and Białystok's location - on the eastern fringes of Poland and the European Union - were interpreted by participants as symbolically significant. The city emerged as a meeting place for cultures, a space for dialogue, and a reinterpretation of Eastern European identity. Many respondents perceived the festival as a gesture of invitation and openness from Poland, allowing them to see Białystok as a place resonating with their own cultural heritage (Zenker, Braun, 2017).

Some approached this with more detachment, pointing to the complexity of the concept of "the East" and the need to consider contemporary political and social differences. However, the dominant tendency was a positive reinterpretation of peripherality as an asset - a space that is different, yet significant and creative.

The conducted study, focusing on the role of the international "Direction East" theatre festival in building Białystok's brand from the perspective of foreign participants, provides important insights that resonate with existing theoretical frameworks of place branding, while offering new perspectives. The three-phase process of city perception transformation, from initial unawareness or stereotypical perception, through dynamic re-evaluation during the festival, to an unequivocally positive post-festival image, confirms Pine and Gilmore's (1998) concept of the experience economy. Participation in the festival was not merely passive consumption of events but a multidimensional aesthetic and educational experience that activated all four dimensions of experience, leading to deep engagement and a lasting change in perception. A key element is the dominant role of organizational professionalism and atmosphere in shaping a positive city image. The high quality of organization, attention to detail, technical competence, and the commitment of the organizing team, repeatedly

emphasized by respondents, align with Richards and Wilson's (2004) theory. According to this theory, the quality of event execution directly translates into the host city's image, building trust and credibility. Moreover, the specific atmosphere of the festival - described as open, dynamic, and conducive to building relationships - along with intense emotions accompanying the reception of performances and interactions with the audience, constituted a key "meaning generator" as per Smith (2012). It was precisely these emotional and social interactions, and not just artistic content, that endowed Białystok with deeper meaning, transcending purely functional associations with the city.

The study also highlights the symbolic weight of Białystok's geographical and cultural location. The festival's name "Direction East" and the city's position on the eastern fringes of Poland and the European Union, perceived by participants as a symbol of openness and a space for intercultural dialogue, confirm Zenker and Braun's (2017) thesis on the importance of cultural context in place branding. Białystok, from the position of a city previously marginal in international perception, gains the status of a place resonating with the participants' own cultural heritage, which is particularly significant in a region with a complex history and identity. This is a departure from the stereotypical perception of peripherality, towards re-defining it as an asset - a creative and significant space.

The research results indicate specific mechanisms by which the "Direction East" festival transforms experiences into value for the city brand. The ambassadorial effect, consisting of spontaneous recommendation of the festival and the city by participants in their countries of origin, is consistent with Anholt's (2006) "cascading effect" concept. Furthermore, established international relationships and partnership projects attest to the lasting impact of the event, extending beyond its temporal scope. The discovery of Białystok's multicultural roots strengthened its identity as an open and historically rooted place. The respondents' postulated stronger integration of the festival into the urban fabric (parades, performative actions, festival club) confirms Richards and Wilson's (2004) theory on the importance of integrating cultural events with urban space to increase visibility and social engagement.

6. Summary and references

The presented study makes a significant contribution to place branding theory, especially in the context of the role of cultural events in shaping the image of cities with a specific geopolitical location. The results unequivocally show that an international theatre festival can act as a powerful catalyst in the process of city perception transformation, particularly for centers with low recognition or those burdened by stereotypes. The identified three-phase process of image change (unawareness/stereotypes → positive image) confirms and expands the understanding of place branding dynamics, emphasizing the role of aesthetic and

educational experiences in the place brand building process (Pine, Gilmore, 1998). This suggests that festivals not only communicate the characteristics of a place but actively construct a new cognitive reality for their participants.

The research findings highlight that the most lasting memories and strongest associations with the city of Białystok were emotional in nature and related to personal interactions and spontaneous gestures from the audience. This finding provides important confirmation for the concept of destination brand equity (Konecnik, Gartner, 2007), indicating that in building loyalty to a place brand, the emotional dimension often outweighs rational assessments. Additionally, this strengthens Smith's (2012) perspective on cultural events as "meaning generators" that, through emotions, create deep connections between people and place.

The International Direction East Theatre Festival in Białystok significantly influences the perception of the city. The study showed that discovering Białystok's multicultural roots generates strong identity connections among participants, which strategically transforms the perception of "the East" from a geographical feature into a unique asset for border cities. Crucial for a positive city perception is the festival's high level of organizational professionalism, which builds its credibility and forms the foundation for complex emotional associations with the place brand. Moreover, investments in high-quality participant experiences result in spontaneous promotion of the city upon their return, creating a so-called "ambassadorial effect" - a more effective and credible form of word-of-mouth marketing than traditional campaigns.

The results of the conducted research allow for the formulation of a number of practical recommendations for theatre managers and local government officials responsible for city branding activities. These conclusions, however, also form the basis for developing good practices in managing various cultural institutions. A key factor in building a competitive advantage is the high quality of event organization. Cultural institutions should invest in the competencies of technical and organizational teams, ensure efficient logistics, and foster a friendly working atmosphere. This not only raises the standard of the event itself but also strengthens the institution's image as a trustworthy partner.

Another important element is building an engaging festival atmosphere. The openness and hospitality of the organizers and the unique atmosphere of the event encourage participants to return to the event in the future. Cultural institutions should consciously create an atmosphere conducive to interactions among artists, audience, and organizers, for example, through post-performance discussions, workshops, or program consultations. This fosters connection with the audience and strengthens their loyalty to the institution.

Festivals help in developing international cooperation. Cultural institutions can use artistic events as a starting point for building lasting partnerships, exchanging artists, and joint projects, which enriches the artistic offering and strengthens the institution's position in the international cultural market.

The research results also indicate the significant role of the so-called ambassadorial effect. Satisfied participants can spontaneously recommend the festival in their home countries, which is a valuable element of word-of-mouth marketing. Institutions can/should consciously strengthen this effect by building relationships with artists and guests through dedicated promotional materials, loyalty programs, or networks of ambassadors who promote the institution's brand in their environments.

An important issue is also professional visual communication and promotion. Communication strategies should be planned to include both digital media (e.g., online activity, social media, short live reports, broadcasts, re-broadcasts) and traditional media (e.g., posters, banners, flyers) to increase event recognition and strengthen the institution's image.

In the context of the international nature of cultural events, it is also worth emphasizing the importance of linguistic accessibility. Organizers should ensure a high level of live translation, subtitles for performances, and promotional materials in various languages. Attention to translations increases event accessibility and helps the institution reach international participants.

The integration of cultural events with urban space is an important element in building the institution's relationship with the local community. Cultural institutions can extend their events beyond the institution's walls, organizing performative actions, concerts, or parades. These activities help reach new audiences and strengthen the organizer's image as an active participant in the cultural life of a given city.

The proposed implications are practical in nature and point to specific actions that cultural institutions can take to increase the attractiveness of their events and build lasting relationships with artists and audiences, as well as support local governments in the process of creating a recognizable city brand.

The use of in-depth interviews as the main research technique is associated with certain limitations that should be critically considered in the context of interpreting the results. The first limitation is the subjective nature of the data, which reflects the individual perspectives of respondents, potentially influenced by situational factors, social expectations, or power relations between the researcher and the research participants (Hammersley, Gomm, 2008). The second significant limitation is the inability to generalize the findings to a broader population, which results from the non-random sampling and its limited size. The study focuses on the depth of analysis at the expense of its breadth, which is characteristic of a qualitative approach (Smith, 2017). A potential source of error may also be the language barrier, despite the use of professional translation. Some cultural and linguistic nuances might have been lost in the translation process, which poses a challenge in intercultural research (van Nes et al., 2010). Awareness of these limitations led to the implementation of strategies to minimize their impact, such as data triangulation (both data sources and data collection methods), participant verification, and researcher reflexivity (Denzin et al., 2017).

The analysis of the conducted research revealed several significant gaps that provide valuable directions for future scientific explorations in the field of place branding and the impact of cultural events. The current study, focusing on perceptions during and after the festival, does not include long-term monitoring of branding effects. It is necessary to conduct longitudinal studies that would monitor the permanence of changes in Białystok's perception over a longer period to assess the long-term impact of the festival on the city's brand.

The analysis carried out in this work was limited to the perspective of participants from international artistic ensembles. In future research, it is essential to include a wider range of stakeholders, such as the local community, city authorities, and business partners. This will enable a more comprehensive understanding of the festival's impact on the city's brand and allow for understanding the interdependencies between different stakeholder groups.

Furthermore, it would be worthwhile to compare the analyzed case study with other theatre or cultural festivals. Future research could adopt a comparative approach to identify best practices, universal branding mechanisms, and specific factors for success or challenges in the context of different urban and cultural environments.

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THE INFLUENCE OF DIGITAL CONSUMERS' BEHAVIOUR ON ENVIRONMENTAL AWARENESS IN POLAND

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Purpose: The aim of the article was to explore the influence of digital consumer behavior on their environmental awareness in Poland.

Design/methodology/approach: The research was conducted using a quantitative survey method via the SurveyMonkey platform. The sample included 1,243 Polish respondents of diverse age and gender, who assessed digital behaviors and environmental awareness using a five-point Likert scale.

Findings: The study confirmed a positive relationship between digital consumer behavior and environmental awareness. Younger and more digitally active respondents demonstrated higher ecological consciousness, with notable differences based on age and gender.

Research limitations/implications: The study was limited to a Polish sample, which may restrict the generalizability of findings to other cultural or technological contexts. Future research could include cross-national comparisons or qualitative insights.

Originality/value: The paper offers new insights into how digital consumer behavior shapes environmental awareness, particularly in the context of an emerging digital society. It highlights the role of demographic variables and suggests targeted digital education strategies.

Keywords: digital consumer behavior, environmental awareness, Poland.

Category of the paper: research paper.

1. Introduction

In recent years, environmental awareness has emerged as a significant factor shaping consumer behavior worldwide. As concerns about climate change, resource depletion, and environmental degradation continue to grow, individuals are increasingly incorporating sustainability considerations into their purchasing decisions. This shift is particularly evident in digital consumers' behavior, where online platforms provide both access to information and opportunities for conscious consumption. In Poland, a country undergoing dynamic digital transformation and growing environmental consciousness, these trends intersect in unique ways.

In the era of accelerating digitalization, consumer behavior is undergoing profound transformation. Technological advancements are not only reshaping purchasing habits, but also influencing how individuals perceive their responsibility toward the natural environment. As consumers increasingly shift their activity to online spaces—using e-commerce, digital services, and mobile applications—new challenges and opportunities emerge for fostering environmental awareness. The intersection of digital behavior and ecological consciousness becomes a critical area of investigation, especially in the context of sustainable development.

This paper presents original empirical findings based on a nationwide survey of Polish digital consumers, offering novel insights into the intersection of digital behavior and environmental awareness. By focusing on demographic dimensions such as age and gender, the study provides a unique contribution to the existing literature on sustainable digital consumption in the context of Poland's evolving digital landscape.

2. Literature review

2.1. Environmental Awareness

Scientific literature defines environmental awareness as the level of human concern for existing environmental problems and related issues (Zheng, 2010). Environmental awareness also represents the responsibility of the entire community—as an integral part of nature—to ensure that current and future generations can live in a clean, safe, and healthy environment while adhering to established ecological principles and norms (Lewis, 2018). It has been observed that the higher the level of environmental awareness, the more often consumers are motivated by financial factors and personal preferences aimed at improving the state of the natural environment (Szeberényi et al., 2022). However, it is worth noting that this does not always translate into eco-friendly actions. Ariffin et al. (2016) adds that environmental awareness also includes people's understanding of problems occurring in the natural environment, as well as the need to resolve them or contribute to preventing harmful situations from arising in nature. Following this line of reasoning, it can be concluded that environmental awareness is not only the responsibility of an individual, but of the entire community, which can shape a shared way of thinking and work toward developing concrete actions in the context of environmental protection (Gajdzik et al., 2024a).

Environmental awareness is a key element in shaping people's ecological mindset. An ecological approach entails opposing the perception of humans as superior to nature—those who aggressively exploit the natural environment without concern for future generations and consider themselves as higher or better beings compared to other organisms. Environmental awareness can also be understood as being closely linked to the highest level of societal

engagement in environmental issues and the willingness to make sacrifices for environmental protection (Moon et al., 2016).

It is worth noting that the shift toward fostering environmental awareness among people is made possible through ecological solutions aimed at achieving sustainable coexistence between humans and nature (Baviskar et al., 2024). Environmental awareness can be developed through reliable environmental education and by informing consumers, and an increase in this awareness leads to the adoption of environmentally friendly actions (Ober et al., 2022). Alongside the advancement of modern technologies, there is a noticeable increase in economic awareness among consumers (Gajdzik et al., 2023a). New technological solutions bring a new dimension to efforts aimed at raising the level of environmental awareness among consumers and can help shape responsible digital consumer behavior.

2.2. Digital Consumers' Behavior

In today's world, technological development and its numerous effects accompany us every day in virtually all activities. Technological progress has shaped us into digital consumers. Many of us have adapted our daily lives to the digital reality. Nowadays, the Internet serves us on many levels—not only for leisure, but also for shopping, placing orders, communication, or handling official matters (Kim et al., 2023; Wolny, 2015). The possibilities offered by the Internet are virtually unlimited. Consumers often prefer to rely on information found online rather than on their own shopping experiences (Kucia, 2016). The need for consumers to adapt to digital reality fosters the development of specific digital behaviors.

The concept of digital consumer behavior should be understood as specific purchasing patterns and habits of consumers in the digital environment (Alkadrie, 2024; Yuruk-Kayapinar, 2020). This can be understood as an organized, sequential set of actions and responses to stimuli that occur in the digital space, driven by the desire or need to satisfy consumer needs (Jaciow et al., 2011). Understanding the digital consumer involves accepting innovative technological solutions such as chatbots, VR, AR, or widely applied artificial intelligence. It is also worth noting that the technological environment, including the Internet, significantly influences digital consumer behavior. Digital consumers demonstrate such behaviors by making purchasing decisions, shopping online, using online services, engaging with mobile (shopping) applications, and actively participating in digital consumer life (Van Nasir et al., 2024; Zhao et al., 2024). In recent times, it has been observed that e-services such as e-commerce, e-banking, e-government, and e-culture, as well as highly popular subscription-based services, have had a significant impact on shaping digital consumer behavior (Kol et al., 2024; Wolny, 2019; Mshvidobadze, 2024; Szojda, 2024). A number of positive factors—such as ease of use, 24/7 accessibility, and attractive pricing—undoubtedly play a key role in encouraging consumers to use digital technologies more frequently. Behaviors supported by digital technologies, artificial intelligence, and cloud-based solutions strongly influence consumer loyalty, as well as the patterns and level of their engagement (Gummerus et al., 2012).

Consumer behavior is also shaped by a range of individual factors, such as motives, attitudes, habits, and emotions (Jaciow et al., 2022). Moreover, digital consumer behavior is strongly influenced by external factors such as social norms and rules, the level of technological infrastructure development, or regulatory policies. These influences also contribute to the development of environmental awareness. The combination of individual and external factors can shape environmentally friendly consumer attitudes, which result from a sense of personal responsibility rather than solely from social pressure (Joshi et al., 2015).

3. Methods

In order to empirically explore the impact of digital consumer behavior on environmental awareness, a structured questionnaire was designed based on validated constructs from the reviewed literature and adopted to the context of Polish consumers. The digital consumer behavior measurement was adopted from Vatolkina et al. (2020), Fakieh et al. (2023) and Ma et al. (2022). The environmental awareness items were adopted from Barragan-Sanchez et al. (2020) and Laaber et al. (2023).

The study was conducted by the Research and Development Centre of the University of Economics in Katowice on the SurveyMonkey research platform, which has a database of approximately 10,000 potential respondents. It was carried out between 18 November 2024 and 27 January 2025. The research was conducted on a sample of 1243 respondents. The study comprised 51.1% women and 48.9% men. The largest age group among respondents was individuals aged 65 and older (23.4%), followed by those aged 35-44 (19.2%) and 45-54 (16.8%). The smallest age group comprised respondents aged 16-24 (11.0%). The majority of respondents had higher education (49.2%) or secondary education (38.1%). Participants with vocational and primary education accounted for 10.4% and 2.3% of the sample, respectively.

In the initial phase of the study, a pilot survey was conducted to ensure the quality of the research tool. A total of 20 respondents were selected to assess the preliminary version of the questionnaire, which allowed for evaluating the content and validity of the included questions.

Respondents evaluated each statement using a five-point Likert scale, ranging from “strongly disagree” (1) to “strongly agree” (5), allowing for consistent and scalable measurement of attitudes and behaviors.

After conducting the pilot study, minor linguistic corrections were made to improve the clarity and readability of the tool, which consequently enabled the enhancement of the questionnaire and enriched its content. Before the main study, participants were presented with a declaration of anonymity and confidentiality. The objectives of the study were outlined, along with the manner in which the results would be disseminated. Additionally, respondents were given the opportunity to contact the researchers via email.

The research findings used in this article are partially derived from the scientific studies conducted as part of the research project titled Digital Maturity of Market Entities in Poland, in which the author is a participant.

4. Results

The aim of the conducted study was to assess the level of environmental awareness among digital consumers in Poland and to examine how their behavior in the digital environment influences their perception of and willingness to engage in pro-environmental actions. The analysis of the data was carried out with consideration for demographic variables such as gender and age, which allowed for the identification of significant differences in attitudes toward environmental issues in the context of digital technology use. The results presented in eight tables provide a detailed overview of the relationship between digital activity and environmental awareness among contemporary consumers.

The majority of respondents (over 50%) recognize the impact of digital technologies on the environment, with men more likely than women to agree with this statement. It can be assumed that men's higher level of digital activity, more frequent use of modern technologies, and greater exposure to technological information positively influence their environmental awareness. In contrast, women more often express a lack of clear opinion, which may indicate limited access to specialized content or a lower level of engagement in digital communication channels related to ecology (Table 1).

Table 1.

Respondents' Awareness of the Impact of Digital Technologies on the Environment by Gender (in %)

Item	Total	Respondents by sex	
		Women	Men
Strongly disagree	9.0	10.6	7.4
Disagree	10.7	12.9	8.4
Neither agree nor disagree	28.3	28.8	27.8
Agree	39.3	37.3	41.3
Strongly agree	12.7	10.4	15.1

Source: own study.

Younger digital consumers – especially those aged 16-34 – demonstrate higher environmental awareness. These groups are more active in the digital environment, use applications, social media, and online content, which facilitates exposure to educational campaigns, green marketing, and eco-friendly products. In contrast, older individuals (65+) show lower levels of awareness, which may result from limited participation in the digital world or difficulties accessing modern information tools (Table 2).

Table 2.

Respondents' Awareness of the Impact of Digital Technologies on the Environment by Age (in %)

Item	Total	Respondents by age					
		16-24	25-34	35-44	45-54	55-64	up to 65
Strongly disagree	9.0	10.2	6.8	3.8	4.8	9.6	16.8
Disagree	10.7	10.9	12.5	12.6	9.6	11.9	7.9
Neither agree nor disagree	28.3	19.0	19.8	24.4	31.7	32.8	36.4
Agree	39.3	41.6	43.2	41.2	38.5	39.5	34.4
Strongly agree	12.7	18.2	17.7	18.1	15.4	6.2	4.5

Source: own study.

This table shows clear differences between women and men in their ability to identify environmentally harmful digital technologies. Men more frequently agree (29.4%) or strongly agree (8.4%) that they are able to indicate which technologies have the greatest environmental impact. In contrast, women more often disagree, with 23.8% strongly disagreeing. This may stem from the fact that men tend to use technology more extensively and are more exposed to technical sources of information. Digital behaviors such as reading specialized content online, participating in tech forums, or accessing industry reports contribute to higher environmental awareness (Table 3).

Table 3.

Respondents' Awareness of Identifying Technologies with the Greatest Environmental Impact by Gender (in %)

Item	Total	Respondents by sex	
		Women	Men
Strongly disagree	19.1	23.8	14.3
Disagree	18.4	20.9	15.8
Neither agree nor disagree	31.1	30.2	32.1
Agree	23.7	18.3	29.4
Strongly agree	7.6	6.8	8.4

Source: own study.

Age significantly affects the ability to recognize environmentally harmful technologies. The best results are observed among respondents aged 25-34 and 35-44, with around 30% agreeing they can identify such technologies. In older age groups (55+), the level of agreement drops considerably, with many respondents lacking knowledge in this area. Younger generations, active in the digital environment and using informational apps, webinars, and educational platforms, are more aware of the environmental effects of specific technological solutions (Table 4).

Table 4.

Respondents' Awareness of Identifying Technologies with Greatest Environmental Impact by Age (in %)

Item	Total	Respondents by age					
		16-24	25-34	35-44	45-54	55-64	up to 65
Strongly disagree	19.1	22.6	20.8	10.5	11.5	18.1	29.6
Disagree	18.4	11.7	15.6	19.7	19.2	17.5	22.3
Neither agree nor disagree	31.1	30.7	24.5	30.7	29.8	38.4	32.6
Agree	23.7	24.8	30.7	25.6	28.8	23.7	13.4
Strongly agree	7.6	10.2	8.3	13.4	10.6	2.3	2.1

Source: own study.

Men are more likely to view the Internet as a tool that increases their climate awareness – 25.8% agree and 9.2% strongly agree, compared to 21.1% and 5.7% of women, respectively. At the same time, women more frequently choose neutral or negative responses. This may suggest that women are less likely to use digital sources of environmental information, or that such content is less accessible or engaging for them. This highlights that the way people use the Internet – e.g., actively seeking educational content – affects their level of ecological awareness (Table 5).

Table 5.

Use of the Internet to Increase Climate Change Awareness by Gender of Respondents (in %)

Item	Total	Respondents by sex	
		Women	Men
Strongly disagree	17.0	19.4	14.5
Disagree	19.6	19.8	19.4
Neither agree nor disagree	32.6	34.0	31.1
Agree	23.4	21.1	25.8
Strongly agree	7.4	5.7	9.2

Source: own study.

Younger age groups (especially those aged 16-34) are much more likely to see the Internet as a source of climate change information. Among respondents aged 25-34, as much as 37.5% gave a positive response. In the 65+ age group, negative answers dominate – 28.2% strongly disagree and only 2.7% strongly agree. This demonstrates that digital activity and proficiency in using new technologies are key factors in accessing environmental knowledge. For younger users, the Internet serves as an informational and educational tool, while seniors are more often excluded from this digital ecosystem (Table 6).

Table 6.

Use of the Internet to Increase Climate Change Awareness by Age of Respondents (in %)

Item	Total	Respondents by age					
		16-24	25-34	35-44	45-54	55-64	up to 65
Strongly disagree	17.0	17.4	17.7	9.7	9.1	16.4	28.2
Disagree	19.6	21.2	16.7	21.4	20.7	17.5	19.9
Neither agree nor disagree	32.6	27.0	28.1	33.6	29.3	37.3	36.8
Agree	23.4	27.7	27.1	24.8	31.7	22.6	12.4
Strongly agree	7.4	6.6	10.4	10.5	9.1	6.2	2.7

Source: own study.

Research reveals that men are more confident in their ability to take action. 27.1% agree and 9.2% strongly agree that they can reduce the negative environmental impact of digital technologies. Women more often express a lack of belief in such influence, with 23.8% strongly disagreeing. This may be related to lower technological confidence or engagement in digital educational or environmental activities, which in turn reduces their sense of agency regarding environmental impact (Table 7).

Table 7.

Perceived Ability to Mitigate the Negative Impact of Digital Technologies on the Environment by Gender of Respondents (in %)

Item	Total	Respondents by sex	
		Women	Men
Strongly disagree	19.1	23.8	14.1
Disagree	19.2	21.1	17.3
Neither agree nor disagree	32.3	32.3	32.3
Agree	22.3	17.6	27.1
Strongly agree	7.2	5.2	9.2

Source: own study.

The highest sense of environmental agency is reported by people aged 35-44 – 44% give positive responses. This is a highly digitally active group, often engaged in professional and social life through online tools, which reinforces both awareness and responsibility. In contrast, in the 65+ group, only 2.1% strongly agree they can take action, while 29.9% strongly disagree. Limited digital activity among seniors directly correlates with low perceived agency and reduced engagement in pro-environmental behavior related to technology use (Table 8).

Table 8.

Perceived Ability to Mitigate the Negative Impact of Digital Technologies on the Environment by Age of Respondents (in %)

Item	Total	Respondents by age					
		16-24	25-34	35-44	45-54	55-64	up to 65
Strongly disagree	19.1	21.9	21.9	10.5	11.1	16.9	29.9
Disagree	19.2	16.1	14.6	20.6	16.3	19.8	24.4
Neither agree nor disagree	32.3	32.8	24.5	31.5	35.1	37.9	32.3
Agree	22.3	24.8	30.7	23.1	28.4	20.9	11.3
Strongly agree	7.2	4.4	8.3	14.3	9.1	4.5	2.1

Source: own study.

In conclusion, digital consumer behavior has a significant impact on environmental awareness. Individuals who are more active in the digital world—particularly younger generations and men—demonstrate a greater understanding of the environmental impact of technology and a stronger sense of responsibility for their consumer choices. The Internet and digital technologies represent not only a potential source of environmental risks but also a powerful educational and motivational tool. The research results highlight the need for a diversified approach to educational efforts—it is essential to support the digital competencies of women and seniors so they can actively participate in the digital transformation with sustainability in mind.

5. Discussion

The findings of the conducted study offer compelling evidence that digital consumer behaviors play a significant role in shaping environmental awareness in Poland. The data analysis reveals a clear correlation between the intensity of digital activity and the level of an individual's environmental awareness, which—when considered through variables such as gender and age—provides valuable insights in the socio-demographic context. These findings are consistent with the main objective of the article: to examine how behaviors in the digital environment influence environmental awareness and the willingness to engage in pro-environmental actions.

Firstly, it is evident that demographic characteristics, especially age and gender, substantially differentiate digital consumers in terms of their ecological awareness. Although researchers emphasize that digital consumer behaviors (including the level of environmental awareness) increasingly surpass traditional ones not only among the youngest age groups (Solis et al., 2023), it is the young respondents (16-34) who demonstrate the highest level of environmental awareness and the greatest activity in the digital environment. This group shows greater readiness to identify environmentally harmful technologies and utilize the Internet as a key source of information on climate change. This may result from their natural immersion in the digital ecosystem, which facilitates access to environmental campaigns, green content, and sustainable brand narratives. These findings are consistent with the results of the study by Jaciow et al. (2021), who found that Generation Z consumers, deeply embedded in digital communication channels, demonstrate a high level of ecological engagement.

Gender-based findings reveal an intriguing dynamic. Men consistently reported higher levels of environmental awareness linked to digital behavior, such as recognizing harmful technologies or believing in their individual ability to mitigate environmental impact through digital choices. This may stem from more frequent use of technical tools, exposure to specialized sources, or higher self-assessed digital competence. Conversely, women more often express uncertainty or disagreement, suggesting a potential gender gap in digital-environmental literacy that requires targeted educational strategies. Brough et al. (2016) arrived at interesting and notably different conclusions, suggesting that men are less likely to engage in pro-environmental actions due to perceiving them as "unmanly," while their environmental awareness is shaped by a range of contextual factors (e.g., innovation, functionality). When digital consumption is associated with utility, it becomes socially acceptable and thus easier for men to identify with ecological values. In contrast, women are much more likely to express their environmental awareness through social, emotional, and normative factors rather than through digital consumption itself (Zelezny, 2000; Hwang, 2020).

Furthermore, the data confirm that the Internet serves as both a tool and a barrier to environmental awareness. Modern technologies in themselves do not generate pro-environmental values — however, their use can facilitate the activation of such values. Developed digital consumer behaviors can support efforts aimed at reducing physical consumption (e.g., using e-services instead of material products) and promote decision-making aligned with ecological knowledge (Neza et al., 2023; Zia et al., 2022; Court et al., 2020). For many respondents—especially the younger cohort—it is a key platform for acquiring knowledge, raising awareness, and even engaging in climate-oriented activism. However, for older users (55+), the Internet remains an underutilized resource, largely due to digital exclusion or low digital literacy. This discrepancy reinforces the necessity of inclusive digital education, particularly for seniors, to ensure equitable access to environmental knowledge and participation in sustainable practices. The research findings are supported by the study of Laaber (2023), which demonstrates that digitally mature consumers navigate online environments more effectively and make more thoughtful, conscious decisions. Wolny et al. (2025) also confirmed that greater consumer engagement in digital services supports a more sustainable approach to environmental issues.

Another noteworthy point is the perception of individual agency. People who are more digitally active and technologically proficient—especially those aged 35-44—are more confident in their ability to reduce the environmental footprint of their online behavior. This sense of empowerment is crucial for turning awareness into action and is reflective of broader concepts in behavioral science suggesting that perceived behavioral control enhances sustainable choices (Joshi et al., 2015a). Lin et al. (2023) note that environmental awareness in digital environments strongly influences purchasing attitudes, especially when consumers perceive both the functional and ecological value of products. Hedonic motivation of consumers related to the intention to use modern technologies also becomes significant. Research confirms that consumers who derive pleasure from modern solutions are more likely to continue using them and to explore other similar innovations (Gajdzik et al., 2024b). Consequently, this also indicates a greater willingness among consumers to implement pro-environmental actions, provided they are associated with modern technologies. Patrzalek (2017), on the other hand, reached different conclusions, demonstrating in her research that environmental awareness among Polish consumers remains low despite their declared proficiency and high activity in the digital environment.

The mechanism explaining the relationship between constructs related to digital consumer behavior and environmental awareness requires further exploration in future research. A possible extension of this topic could involve the application of established behavioral models, such as the Theory of Planned Behavior (TPB), which posits that an individual's actions are shaped by attitudes, social norms, and perceived behavioral control. Applying this theory could help clarify how exposure to digital information (e.g., through e-services or ecological campaigns) influences ecological attitudes and, consequently, leads to actual pro-environmental

behaviors (Ajzen, 1991). Similarly, the Value-Belief-Norm (VBN) model could be used to conceptualize how personal values (e.g., altruism, biospheric concern) interact with beliefs about the environmental consequences of digital consumption, resulting in a moral obligation to act (Stern, 2000).

However, an important limitation of the study is the lack of critical analysis of the environmental costs associated with digital consumption itself. While digital tools may serve as channels for promoting ecological awareness and enabling sustainable lifestyles, they also generate significant environmental externalities. These include the carbon footprint of data centers, energy consumption associated with cloud services, and the growing problem of electronic waste (e-waste) stemming from short product lifecycles of digital devices. Ignoring these factors may lead to an overly optimistic assessment of the digital transition. As Court and Sorrell (2020) have shown, the digitalization of goods often leads to rebound effects, where efficiency gains are offset by increased overall consumption. Including a discussion on the double-edged nature of digital technology—as both a facilitator of sustainable behaviors and a contributor to environmental degradation—would provide a more balanced and comprehensive perspective. Future research should therefore explore the net environmental impact of digital consumer behavior, weighing both benefits and hidden costs.

Taken together, the findings emphasize that digital consumer behavior is not neutral—it has tangible implications for environmental engagement. This includes both passive influences, such as exposure to environmental content, and active ones, such as seeking out eco-friendly brands or engaging in online sustainability communities (Gajdzik et al., 2023a). Additionally, it is worth emphasizing that strong consumer engagement in digital activities contributes to the growth of environmental awareness (Dat et al., 2024).

6. Conclusions

The study, conducted on a representative sample of 1243 Polish respondents, confirmed that digital consumer behavior significantly influences environmental awareness. Younger individuals and men—who are generally more digitally active—demonstrated a higher level of ecological consciousness. Respondents who more frequently engage with digital tools such as online shopping, e-services, and educational platforms tend to exhibit stronger awareness of environmental issues and greater readiness to take action. The results also revealed that age and gender moderate this relationship: younger participants show greater trust in online information sources, and men are more likely to identify specific environmentally harmful technologies. However, the study also identified potential gaps in digital-environmental literacy among women and seniors, suggesting the need for inclusive digital education strategies.

The findings of the study confirm that digital consumer behavior plays a pivotal role in shaping environmental awareness. Technologically proficient and digitally active individuals are more capable of identifying ecological threats and are more willing to engage in pro-environmental behaviors. This demonstrates that digital environments are not only platforms for commerce, but also powerful tools for shaping sustainable mindsets. However, disparities based on age and gender emphasize the need for targeted support in developing digital competencies and ecological education. In an increasingly digital society, promoting responsible online consumer behavior is essential for fostering broad-based environmental awareness and advancing sustainability goals.

In future research, stronger theoretical anchoring is recommended to better explain the causal mechanisms underpinning the observed correlations. The integration of models such as the Theory of Planned Behavior (TPB) or the Value-Belief-Norm (VBN) theory could facilitate a more holistic understanding of how digital exposure influences not just awareness, but actual behavior. Furthermore, to present a balanced view, it is crucial to also consider the environmental footprint of digital infrastructure itself—including energy consumption, carbon emissions, and e-waste. Only by addressing both the opportunities and the trade-offs of digital consumerism can a truly sustainable digital transformation be envisioned.

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POLISH LANGUAGE MODELS IN BUSINESS AND PUBLIC SECTOR: A STRATEGIC PERSPECTIVE

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Purpose: The aim of this article is to analyse the first two Polish language models (Large Language Models) from the point of view of strategic dimensions of implementing national (LLMs) in the business and public sector. The study outlines both the possible benefits of implementing LLMs in Polish organisations and the challenges of their implementation.

Design/methodology/approach: The research was conducted using a qualitative approach with three techniques - literature analysis, case study analysis and semi-structured in-depth interviews. Eight interviews were conducted with key persons responsible for the management and establishment and development of the two national language models.

Findings: Both models demonstrate different approaches in building, further developing and implementing national LLM models. Regardless, both play a strategic role in Poland's digital sovereignty. The results underline the importance of LLM not only in the context of technological innovation, but of building digital capacity in business and public administration.

Research limitations/implications: Although the results of the research provide many contested insights they have their limitations. The small sample size limits the possibility of generalisation. Future research should take into account the triangulation of other methods.

Practical implications: The practical implication is the ability to use presented framework to design, development and implementation of national LLMs. The research can inspire further research on the implementation of LLMs in public institutions and business in the context of sovereign technological solutions.

Social implications: The article can encourage critical reflection on the social role of national LLMs including ethical issues and those related to the development of digital competence.

Originality/value: The article offers an innovative contribution to the development of first national language models. The research shifts the analytical perspective towards strategic, institutional and governance dimensions. The value of the research is its interdisciplinary approach, which focuses on the development and implementation of LLMs in the national infrastructure.

Keywords: Large Language Model, Digital Transformation, Technological Sovereignty, Public-Business Sector Innovation, AI in Poland.

Category: Research paper.

Introduction

For several years, there has been an increase in both the availability and extent of use of large language models (LLMs) based on deep neural networks (Zubiaga, 2024). Although the development of LLMs began with Google's creation of the BERT model, it was only with the introduction of Chat GPT in 2022 that the development of large language models worldwide expanded (Ravichandiran, 2021; Wang et al., 2024). LLMs offer their users assistance to improve their every day work and personal lives. Still, their role, principles of operation and application are only fully understood by expert communities. In the literature on the subject, LLMs are often described in technical, specialised language and in a fragmented manner, making it difficult to access the knowledge about their practical application. Advanced artificial intelligence systems are characterised by being trained on extensive text corpora with parameters that often exceed hundreds of billions (Jiang et al., 2020). The increase in computational power and the use of multiple and diverse neural network architectures to handle large datasets, allow models to perform various tasks more accurately (Wickramasekara, Scanlon, 2024). LLMs processing natural language have become capable of generating human-like text and understanding complex prompts with high precision (Wang et al., 2024).

LLMs are changing the way users interact with computers, primarily because these models are able to analyse complex linguistic structures and increasingly take context into account and formulate human-like responses (Kietzman, Park, 2024). It is worth emphasising that despite these advances, their ability to map deeper cognitive processes is still limited. Large language models show some degree of sensitivity to representations of other people's mental states (so-called false belief reasoning), but the ability to do so is still limited and does not match the human ability to understand other people's beliefs. As the results of the Trott et al. (2023) study indicate, the linguistic statistics in the LLM training data alone are not sufficient to fully represent the complex aspects of human theory of mind (Carlson et al., 2013). While humans in a test based on the False Belief Task achieved a correctness of 82.7%, the largest LLM model tested achieved a score of 74.5%. Importantly, the model's behaviour did not fully explain people's behaviour.

Large-scale LLM language models are not only used by end users as private assistants but play an important role in wider social and professional contexts. Their versatility and new functionalities are influencing their use in many different disciplines (Retkowsky et al., 2024). They also have an increasingly strong impact on business as well as public service organisations (Chatham et al., 2024, Islam, Islam, 2024). Nowadays, although large, elaborate, multifunctional language models such as ChatGPT, Deepseek, Gemini dominate, it is possible to observe the development of smaller, including national models that seek to compromise between operational efficiency and accessibility (Żmigrodzki, 2025). Among others, the following have developed their models: Netherlands (GPT-NL), Italy (Modello Italia),

France (Mistral), Taiwan (TAJDE), Singapore (SEA-LION), Saudi Arabia (ALLaM), United Arab Emirates (JAIS), Spain (MarIA) (SifHCAI, 2024).

National language models emphasise the recognition of language-specific ambiguity and semantic complexity. They are designed so that they can reflect the specific linguistic, cultural, legal and social characteristics of a country and can be particularly attractive not only for individual users but especially for business and the public sector, administration, health, education, the judiciary (SifHCAI, 2024). National LLMs aim to strengthen digital sovereignty and deliver services in line with the local priorities (Pandey, 2025). They are becoming a key component of local innovation ecosystems (Chiarello et al., 2024; Ferraris et al., 2025). Regardless of whether LLM models are designed for national use or any other context, they still have a strong tendency to generate (or hallucinate) false content and information (Wickamasekara et al., 2024), often biased and reinforcing existing stereotypes (Gallegos et al., 2024). As Leong and Snug (2024) emphasise, the hallucinations that LLM models generate are structurally related to the existing social prejudices.

Given their rapid development and deepening integration with human and organisational activity and their increasingly widespread use in business and the public sector, it is particularly important to conduct research related to the implementation of language models. In particular, the development of national language models, which constitute a new alternative in management strategies and the digital transformation of organisations, is under-researched. Their implementation creates both opportunities and challenges for all organisations. Therefore, this study focuses on the following research questions:

RQ1. What are the key goals, characteristics, and directions of the future changes of the first two Polish LLM models?

RQ22. How can business and the public sector use models in strategic management?

By answering these questions, the article will provide a better understanding of the importance of national language models for the digital transformation of business and public organisations, their impact on management strategies, and the challenges of their implementation in Polish organisations.

Strategic applications of language models in the business sector

Business instantly recognised the potential and importance of large language models (LLMs) as important transformational and developmental tools. Initially, LLM models accelerated the execution of operations in organisations, streamlined decisions and enhanced interactions with users and customers. As time passed and large language models became more functional, companies began to benefit more and more from their use. Automation began to streamline workflows that had previously been performed manually, enabling companies to

focus resources on higher-value tasks (Fahland, 2025; Maarouf, Feuerriegel, Pröllochs, 2025). As a result of the development of LLMs, organisations very quickly recognised their potential. The new possibilities of integrating LLMs, especially in the context of business process management, have led organisations to seek to optimise their operational processes (Estrada-Torres et al., 2024).

The development of natural language processing (NLP) capabilities has translated into analysing vast amounts of structured and unstructured data and generating human-like responses. The introduction of advanced chatbots and virtual assistants that answer questions, handle requests and claims has not only improved customer interaction and communication (Dash, Bakshi, 2019) and helped to improve customer satisfaction (Janssen et al., 2020).

In addition to the deployment of chatbots for customer service processes, the automation of business processes has significantly advanced predictive analytics, knowledge management and strategic decision-making. The ability to analyse large amounts of information quickly, has allowed companies to identify trends, generate insights and make informed decisions that drive business growth. With the democratisation of the access to information, the use of extensive data and knowledge that can be applied for market analysis, idea generation and research initiatives has become more accessible and widespread (Chang et al., 2023; Szilágyi, Tóth, 2023; Fahland et al., 2025). As a result of these processes, business organisations have improved their operational efficiency, increased their quality of service, competitiveness and innovation and, basically, reduced costs (Chen et al., 2025).

The qualitative breakthrough that has occurred in the development of language models has opened up a shuttle of new practices and competences for business that were previously attributed only to human intelligence (Makridakis et al., 2023). Chiarello and co-authors (2024) recognise the increasingly complex and multidimensional role of language models and their application in the business environment. The high flexibility of LLM models is translating more and more into increased personalisation of services, supporting decision-making, increasing operational efficiency and fostering innovation across sectors. One of the processes undergoing the change under the influence of LLM is the area of human resources management. The models contribute to automatising of HR policies creation, talent acquisition strategies, as well as improving recruitment and selection processes and building and personalising development plans for employees. Administrative processes - day-to-day tasks, communication or team collaboration in automated environments - are strongly transformed under the influence of generative models. LLMs support tasks related to document classification, product and service customisation. They enable the creation of diverse content, including marketing content, its evaluation and selection, as well as the development of content moderation algorithms (Chiarello et al., 2024).

Even more efficiently, they can search and customise information based on user queries. By improving communication and personalising responses, they can provide more tailored experiences for customers (Chen et al., 2024). Finally, they contribute to accelerating informed decisions in a rapidly changing digital landscape (Ilagan et al., 2024).

Research conducted by experts at the Speakleash Foundation (Żmigrodzki et al., 2025) shows that 49.3% of Polish companies surveyed use both open and closed LLM. Chat GPT is by far the most widely used, while Llama, Claude, Gemini or Mistral models are used much less frequently by Polish businesses. Entrepreneurs most often use models for knowledge extraction, creative writing, content summarisation and translation. Models are also helpful in automating communication, sales support or customer service (Żmigrodzki et al., 2025, p. 49).

Large Language Model in public organisation

Advanced AI systems, especially large language models (LLMs), are also making a significant transformation in the public sector (Yang et al., 2024). LLM models are part of a permanent feature of the management and service delivery of public organisations. Their use contributes to improving administrative efficiency and making services more accessible to citizens and increasing their civic engagement (Kleiman, Barbosa, 2024; Yoon, 2024).

Advanced automation and processing facilitate the deployment of virtual assistants and chatbots that improve interactions between citizens and government offices. LLMs provide detailed and relevant answers to citizens through intelligent query processing. As noted by (Pessanha et al., 2024), the use of LLMs allows for faster and more precise service to citizens, mainly by providing more contextual answers to the questions sent. This not only reduces waiting times for information but increases the responsiveness of services (Papageorgiou, 2024) and aptly supports users in the execution of administrative procedures (Gaetano, Diliberto, 2018; Decker et al., 2023). National LLM models, which are specifically trained on local data and adapted to local language, culture or law, become particularly effective in these tasks (SifHCAI, 2024).

Another key application area for LLM in the public sector is data analysis and the generation of insights. Language models can analyse large data sets, identify patterns and predict trends. This translates into better operational optimisation and efficiency in government operations. Administrative decisions can be made in a more informed manner and respond more quickly and accurately to societal needs (Carullo, 2023; de Curtò, 2024). The public health field uses language models to identify health problems to diagnose diseases and suggest potential treatment pathways and therapies, analyse patient data, and support clinical decisions (Thirunavukarasu et al., 2023; Huo et al., 2025).

Mamalis et al. (2024) highlight the role of LLMs in regulatory management, including the interpretation and analysis of complex legal texts. The integration of language models into legal systems allows for more efficient retrieval of relevant provisions, facilitates the interpretation of legislation and supports both officials and citizens in navigating legal complexities. For example, specialised LLM models can be used in administration to automatically classify documents, analyse legal precedents or support the drafting of laws.

For example, specialised LLM models can be used by the government to automatically classify documents, analyse legal precedents or support the drafting of laws. The provision of accurate information is enabled by the Retrieval-Augmented Generation (RAG) methodology, whereby LLMs interact with customised datasets (Jeong, 2023) and generate answers based on these. LLMs are also seen as a tool to support training and education of public sector employees. Models can help government employees to better process complex data sets and interpret the legal framework (Zhang, Chen, 2025) or onboarding processes (Ramli, 2025).

LLMs can also contribute to more efficient management of public resources, including the optimisation of energy consumption in administrative buildings and urban planning. By integrating distributed data sources and improving decision-making processes, artificial intelligence supports environmental policies and urban infrastructure management strategies (Zhang, Chen, 2025).

The use of LLMs is also finding its place in educational settings and higher education. It is transformative in that it influences the development of teaching materials, the personalisation of teaching and learning processes, and the design and conduction of research (Kasneci et al., 2023; van Dis et al., 2023; Wang et al., 2024;). The role of LLMs is not only limited to the automation of educational processes, but is hugely influential in changing the paradigm of teaching and learning (Choi, Abdirayimov, 2024; Chowdhury, Chowdhury, 2024).

With the growing role of LLM and the increasing number of applications in many areas, including strategic ones, there are ethical and practical challenges. It becomes necessary to balance the benefits and risks so that the implementation of LLM allows the potential of this technology to be realised.

Methods

The research used a qualitative approach, combining three complementary methods - literature review, case analysis and in-depth individual interviews. Qualitative methodology was used because of its ability to capture the complex, contextual aspects of the phenomena under study. This is particularly important in the exploration of the dynamic processes of the development of local language models. The flexibility of the qualitative approach makes it

possible to adapt the research tools to the specificities of the cases analysed and the themes that emerge (Groenland, Dana, 2019).

The literature review included academic publications, including articles and book chapters available in Scopus, Google Scholar and Web of Science databases, and industry reports on the development and use of LLM models in management in business and academic settings. One of the key elements of the research was a case study (Schwandt, Gates, 2018), in which two Polish Large Language Models (LLMs) were examined in detail. The analysis aimed to understand what needs are fulfilled by the two models on a national basis, to learn about their characteristics, applications in the business environment and the public sector, and further development. Their importance stems primarily from the fact that both models are the first of their kind developed for Polish users and citizens. The models open up new perspectives for digitisation, process automation and technological self-reliance of the country. Seven interviews were conducted in the final stage of the research. The selection of participants was purposive, in line with qualitative research, which allowed detailed and contextual information to be obtained from key people in the projects under study (Bouncken, Czakon, Schmitt, 2025). The respondents included both the creators (authors of the idea), those leading the implementation of both projects and those involved in the project team. The criteria adopted for selecting participants took into account their level of involvement, their role in the project structure and their access to decision-making and operational information related to the development of the LLM. This method of sampling enabled diverse perspectives to be gathered, covering both strategic and technical aspects of project implementation. Due to the expert and specialised nature of the subject matter under study, as well as the limited number of people actually involved in both projects, the research sample was limited. Nevertheless, its composition ensured access to in-depth knowledge, representing different levels of responsibility and perspectives within the projects analysed.

In the case of the first analysed model, the Bielik, four people representing the project team participated in the interviews, while in the case of PLLuM, there were three people, each representing a different consortium member. The interviews were conducted online and moderated based on a prepared scenario. The average interview time was at least 60 minutes, the longest of them took 90 minutes. The respondents were informed about the ethical principles of conducting interviews and assured of anonymity. Each of the interviewees agreed to consciously participate in the interview and its recording. Then the interviews were transcribed and analysed using the Maxqda program. The thematic analysis conducted allowed for systematic coding and identification of recurring patterns and thematic categories.

The triangulation of methods contributed to obtaining a more complete picture of the problems of Polish language models, characterisation of both models, development plans and strategic applications.

Results

Application Both the Bielik and PLLuM form families of models that have been designed for the needs of different user groups. They are designed to meet the goals and needs that flow from both business and the public sector. Both models have variants ranging in size from small models to multi-billion dollar models. The Bielik model was described in the context of potential applications in business, while the PLLuM model in the public sector was described as ready-made instruments to be implemented and deployed by other companies and organisations. However, the author of the paper emphasises that both models already have implementations in both areas. The Bielik has been implemented by, among others, the Poznan Supercomputing and Networking Centre, the EU Council, the Chancellery of the Prime Minister (Poznań Supercomputing Centre, 2025), while the PLLuM model has been implemented by the Comarch S.A. centre (Comarch, 2025). Table 1 presents a summary of the most important features and characteristics of the first two models (family) of Polish Large Language models.

Table 1.
Comparison of the Polish language models LLM - the Bielik and PLLuM

Features	Bielik	PLLuM
Year of creation	2024	2025
Lead time	app. 12 months	app. 11 months
Founding bodies	SpeakLeash Foundation Cyfronet AGH	Consortium: Wrocław University of Technology (consortium leader), NASK National Research Institute, Information Processing Center - National Research Institute (OPI PIB), Institute of Computer Science Polish Academy of Sciences, the University of Łódź, and the Institute of Slavic Studies of the Polish Academy of Sciences
Objectives of the model/ family of models	Support of machine learning research processes, training of a generative, pre-trained transformer model on the basis of the collected data	Support for the development of digital competences, the development of innovation in public administration and business
Number of parameters	from 1.5 to 11 mld (various architectures)	8 to 70 mld (various architectures)
Project funding	A bottom-up initiative, a project supported by the availability of Cyfronet's computing power sponsors (Helios, Athena), Patronite servis	Ministry of Digitalisation, Public funding

Cont. table 1.

Budget	No data	14.5 mln
Access	Free of charge, open source model	Models under fully open licenses; Models under restricted licenses (not allowing commercial use)
Training data	A collection of more than 3 terabytes of texts in Polish, exclusively from open, public sources (e.g. Polish Wikipedia, scientific articles under open licences, collections from the Common Crawl and data from public institutions)	Trained on approximately 150 billion tokens of mainly Polish-language text, comprising internet data, resources acquired through contracts with publishers and instructional data created manually and distilled from other models. In addition, approximately 100.000 human grade samples were used to fine-tune the model preferences

Source: Own study, 2025.

The Polish generative artificial intelligence model Bielik was created by the SpeakLeash Foundation (Bielik, 2025). One respondent noted:

The Bielik was created by our own efforts, thanks to a grassroots social initiative. An initiative that is independent of any entities.

(Respondent 2)

The idea to create a Polish language model stemmed from a growing awareness of the importance of large models and the need to create a tool adapted to the Polish language - including the cultural context. The project team noticed that foreign models could not cope with the Polish language in data processing. The first goal of the project was to create a training dataset. As one respondent emphasised: We wanted to collect one terabyte of data. That was our goal. One terabyte of data, because the scientific studies said that models start just above one terabyte.

For us it was such a first goal to grab a terabyte, to produce and just see this scale of what we can achieve on one terabyte of the Polish data.

(Respondent 1)

The second goal the project set itself was to develop benchmarks that would allow the effectiveness of the model to be measured in the context of the Polish language. This ensured that the Bielik could not only be adapted to the Polish language, but also subjected to rigorous quality testing.

We started doing a language nuance benchmark and that was the other goal. Once we started thinking about the Bielik and training it, we suspected we would create the biggest set of Polish benchmarks.

(Respondent 2)

One of the most important assumptions in creating the model was to create one that could work without the need for global AI solutions. In addition, the developers of the Bielik wanted the model to be able to be implemented locally in organisations. The work started by the team

was initially experimental, as at the time there was a lack of publicly available information on how to create large language models, and many aspects of their construction remained a business secret. The decisive moment for the development of the project was the addition of the Cyfronet team from the University of Science and Technology, which provided the Bielik with the necessary computing power. This led to the creation of the first LLM model, initially in the 1 billion parameter version, which now runs on 11 billion parameters and is able to process and store as many as 32,000 tokens simultaneously. From the beginning, the project was open source, meaning that any user can download and use the model for commercial and research purposes for free.

Now the project team of the Bielik has begun to expand the project's objectives to include cultural and social aspects. The new version of the model, the Bielik 3.0, aims not only to support business, but also to protect and document elements of the Polish culture, including dialects and regional customs:

We now want to address the cultural strands more, because there are fewer and fewer people who can distinguish between white borscht and sour soup, who can recognise different customs.

(Respondent 1)

PLLuM (Polish Large Universal Model) was created as part of a consortium of six partners from the Wrocław University of Technology (leader), the NASK National Research Institute, the Information Processing Centre - National Research Institute (OPI PIB), the Institute of Computer Science of Polish Academy of Sciences, the University of Łódź and the Slavic Institute of Polish Academy of Sciences (Polish Ministry of Digitalisation, 2025). Its main objective was to create an open-source, Polish-language model in line with the responsible development of AI systems. In addition, the project prioritised the development of a prototype application of this model for public administration in the form of a Polish-language intelligent assistant.

The aim of the project was to create a model that is good for the Polish language, over which we first of all have control, we know how to train it, we know how to tune it for the task we want. We are the ones who say what the model can say, what it can't say, and nobody imposes it on us from the outside. And that was the main idea, the core.

(Respondent 1)

The foundation of the model was an extensive database, developed in collaboration with public administrations, publishers and cultural institutions (PLLuM, 2025). The construction of the training corpus covered 100 milliiards of words. It was designed to understand natural Polish, regarding its specificity, history and socio-administrative context. A key aspect of it was to ensure content security, i.e. to minimise the generation of harmful, offensive or toxic speech. PLLuM will play a key role in the digitalisation of public administration and to facilitate the navigation of complex government systems. As a prototype of a citizen assistant, it will support

the operation of the mObywatel [mCitizen] application and facilitate citizens' access to public information and services. The project resulted in a family of the PLLuM models, which consists of 18 versions. They differ in the number of parameters and their purpose. The models can be divided into three variants. The first, a base model, which has undergone language adaptation, understands Polish and can predict subsequent words. The second model, the instructional model, has been trained to perform specific tasks based on instructions. As one interviewee points out:

The instructional model can perform certain tasks. We refer to it as nurtured (aliveness), i.e. adapted to preferences. The model not only responds, carries out tasks, but carries them out in a certain way that we define. For example, according to norms, according to social values, according to expectations.

(Respondent 3)

The third of the family of the models, the dialogue model, was adapted after the nurturing process to interact and talk with users.

Application of the Bielik model family in business

The Bielik models will be useful for text analytics and process automation tasks. This makes them suitable for: a) automated document analysis - e.g. reviewing regulations, contracts, procedures; b) creating summaries - financial reports, ESG reports, market analyses; c) generating marketing content - advertising slogans and content, product descriptions. As one interviewee highlighted: *The Bielik can summarise, analyse, style answers - it does it all, but it doesn't have a built-in fact base. It does, however, make great inferences.* The model is easy to personalise, which makes it possible to tailor its operation to the specifics of a given industry - (...) *if someone gives the Bielik a description of their business and says: come up with a slogan, they can additionally choose the level of creativity of the model.* (Respondent 2).

The Bielik family of models can provide support for knowledge management in an organisation. The Bielik provides opportunities for integration with various systems, e.g. internal databases or analytical tools. According to one respondent, the model gets its wings when it is connected to a knowledge source, e.g. a library system. In this way, companies can automatically search and summarise large amounts of knowledge, create assistants (chatbots) that can support employees in data analysis and subsequent key decision-making, and use the models to automate customer interactions. A useful tool for business is the Bielik's ability to correctly interpret linguistic errors, sarcasm or colloquial style, and it is good at recognising emotions and tone of speech. These functionalities are particularly important for analysing customer feedback, automating the handling of queries or processing corporate communication texts. In this way, it can support companies in monitoring online brand and product opinions, analysing marketing campaigns and their reception or detecting disinformation. As the Bielik

offers the ability to process internal data, which is often of a confidential and sensitive nature, without having to send it to external providers. This feature appears to be crucial for companies that process medical, financial and legal records and for which data and information security is a priority:

The Bielik as an open source system can be downloaded onto their own infrastructure, which ensures that data is not sent to third parties and is not used for further training.

(Respondent 4)

By basing the Bielik family of models on the idea of open source and local operation, companies do not have to incur costs for processing data on commercial providers' servers. For the organisations that work with large data sets, this translates into considerable savings. Companies can create their own AI systems without incurring commercial licensing or token costs, and adapt their Bielik-based models to the specifics of the organisation without licensing restrictions. One respondent stated that:

For large databases, the cost of cloud computing can run into the millions of dollars. Using a local model like the Bielik reduces costs to the level of electricity consumption.

(Respondent 2)

In summary, the Bielik family of models offered as an extension and ethically active solution for AI business applications. The applicability, open source basis and application to applications that are available for outreach is truly an alternative to large language models. hidden for organisations that are subject to confidential data and large repositories of knowledge. The Bielik model not only strengthens processes such as document analysis, knowledge management and marketing automation, but is also a control part with strategic priorities, attachments like data analytics, operational scalability and cost management.

This can lead to an organisation's application, decision-making based on the provision and use of language processing technology without lack of control over their data infrastructure.

PLLuM – application of the model in the public sector

Among the wide range of 18 variants of the PLLuM family of models, licensed (non-commercial) and general-purpose models are available. Licensed models, with a larger corpus, have been trained on large datasets (approximately 150 billion tokens) and are available for research purposes only. They may be applicable in academia, language analysis and prototype implementations in the public administration. Smaller models can be commercially applied in customer automation processes, report generation, or legal text analysis. The access to a variety of models provides institutions and organisations the opportunity to choose and adapt to specific, individual needs and capabilities. These tools can support the public sector in the activities related to automating administrative processes, improving official communication or

supporting citizens in accessing public services. One argument in favour of using PLLuM models is their high linguistic quality. The models were built and then trained on the basis of organic data. This allowed the elimination of linguistic loans derived from direct translations of English-language collections.

There are no calques in the models, there is all the punctuation. If we want to use the model in public administration, we want it to actually use correct Polish, so that there are no calques, this negative transfer of translations, then such a model, which is sensitised to organic instructions, has a definite advantage over other models here.

(Respondent 3)

The texts generated by the model ensure not only linguistic correctness but security, reliability and legitimacy. In the context of administrative applications, these features take on particular importance. The models work with data that has been acquired in accordance with applicable laws, including data protection or copyright regulations.

The PLLuM models are currently in the prototype phase, but will be available for testing for the selected public institutions as early as 2025. The pilot deployments in the public administration services are planned as part of the new HIVE AI project. As part of the integration with the mObywatel [mCitizen] application, its users will be able to receive answers to the questions about official procedures. A citizen assistant, created as part of the project, will assist citizens and officials in the tasks related to searching and processing information. In this case, in the future, it will be possible to apply the RAG (Retrieval-Augmented Generation) technique. It allows the use of external databases and synthesis of answers in the same way as the regular Internet search engines do. Due to this, the model is not based solely on the knowledge recorded in neural structures, but can dynamically operate on the current data and official documents. One of the people responsible for the implementation of the HIVE AI project stated:

Thanks to the cooperation with additional partners, such as COI and Cyfronet AGH, it will be possible to increase computing power and improve the process of implementing the model in practice. The project will allow the entire sector to enter the key stage of the digitisation of public services.

(Respondent 3)

The PLLuM language model reinforces the direction of language models = tailored to the needs of Polish public administration. The wide spectrum of model variants available, enables a flexible and strategic approach of the organisation to digital transformation. The planned integration of PLLuM with the mObywatel platform, illustrates its potential to increase citizen engagement, streamline bureaucratic processes and support information accessibility. The PLLuM model offers not only a technological innovation, but also a tool that is tailored to the modernisation of the public sector.

Discussion

The study results confirm that both the Bielik and PLLuM represent complementary approaches to the development of national language models. The models are tailored to the diverse needs of both public and private sector users. The models differ in architecture, implementation goals and funding modalities, but they share a strategic role in building digital sovereignty and enhancing digital competence. The Bielik model, developed within an open and experimental environment, targets both business and public sector needs. Features such as open access and the possibility of local deployment make it an attractive tool also for small and medium-sized enterprises, or offices. In turn, the PLLuM model, developed in a consortium of research and public institutions, is tailored to the needs of the public administration and state institutions. The model offers a high level of security and compliance with the legal standards.

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However, as Trott et al. (2023) indicate, current models are still limited in their ability to capture deep cognitive processes, such as understanding the beliefs of others. This means that, despite their technological advancement, the use of LLMs should include an awareness of their cognitive and epistemological limitations. According to Pandey's (2025) research, national language models are becoming key components of digital sovereignty of states, offering an alternative to corporate solutions that often fail to grasp local contexts. Based on the local data and preferences, models such as the Bielik and PLLuM can serve as a foundation for responsible and sovereign development of AI.

Summary

Both business and the public sector are subject to the changes initiated by the rapid development of artificial intelligence. AI is constantly changing our world and introducing a revolution linked to large national language models. This research indicates that national

language models, such as the Bielik and PLLuM, are key tools to support the processing and generation of content in Polish. Their use contributes to the development of digital competences and also promotes innovation in the public and private sectors. Importantly, these models play a strategic role in building technological independence and strengthening cyber security, fitting in with Poland's long-term digital sovereignty goals. National LLMs play a multi-faceted strategic role. This role involves alignment with the needs of the public sector and business, especially in strengthening management processes. With their advanced natural language processing capabilities, the models adapt Polish to the socio-cultural context and ensure high-quality information processing. Their functionalities are not only important for easing the burden of routine tasks or increasing the efficiency of employees from both sectors. Moreover, the role of national LLMs takes on particular strategic importance. In addition to providing information and analytical tools, they contribute to a country's technological independence and strategic digital sovereignty. By processing sensitive data within national borders, they provide independence from global models. Their creators and owners are often independent corporations whose models are encroaching more and more aggressively on the private and public sphere of the Polish citizens. These models provide scalable tools for operational efficiencies, customer interactions and knowledge management, especially in the sectors that require the specific Polish language. Companies and the public sector can use LLM to automate services, personalise content and make data-driven decisions.

The development of national LLM programmes, such as the Bielik and PLLuM, carries significant implications in the areas of policy and governance. For policymakers, these initiatives highlight the importance of sustained investment in localised artificial intelligence infrastructure, ethical governance and data sovereignty. National support for open but secure artificial intelligence ecosystems can strengthen strategic autonomy and innovation potential.

In the context of government applications, this is particularly important both for building citizens' trust in the actions of the government and public administration. The question of whether national LLMs should belong to the national critical infrastructure also seems important. Fostering public-private-academic partnerships can accelerate the responsible deployment of artificial intelligence and stimulate further research and development.

Unlike many non-English LLM initiatives, Poland emphasizes distinct entrepreneurial strategies to mitigate data vulnerability and ensure cultural alignment. This study comparatively analyzes entrepreneurial practices and sovereignty outcomes.

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ANALYSIS OF THE LOGISTICAL PROCESS INVOLVED IN SETTING UP A VEHICLE INSPECTION STATION IN POLAND – A CASE STUDY

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Purpose: The purpose of this paper is to detail the steps necessary to re-launch the operations of a District Vehicle Inspection Station in the context of current legislation and administrative procedures. The objective of the paper is to identify the fundamental elements of the logistical process, including the preparation of the technical infrastructure, the completion of the documentation, the procurement of the necessary certificates and the integration with the CEPiK system. The primary objective of this publication is to furnish entrepreneurs and industry specialists with the knowledge necessary to successfully establish or re-establish a vehicle control station in Poland.

Design/methodology/approach: The paper employs the case study method, focusing on the process of reopening a specific District Vehicle Control Station in the Mikołów district. The selection of this method was predicated on its capacity to analyse in meticulous detail the actual logistical, procedural and administrative steps that must be taken in practice. The case study method enables the demonstration of both the formal requirements and the actual difficulties encountered by the entrepreneur, in addition to the solutions that were found throughout the process.

Findings: Consequently, the study yielded the development of a comprehensive procedural diagram for entrepreneurs contemplating the establishment of a vehicle inspection station in Poland. The provision of a practical tool is of paramount importance in supporting the implementation of the process in accordance with current legislation and technical and organisational requirements.

Research limitations/implications: The study does not cover the stage of building a district vehicle testing station, obtaining building permits or purchasing new diagnostic equipment. The scheme has been developed for entrepreneurs who intend to recommence operation of an existing station that meets the requisite technical requirements and is equipped with the necessary apparatus.

Originality/value: The paper's value lies in its practical presentation of a structured scheme of activities. This scheme has the potential to provide real support for entrepreneurs planning to renew the activity of vehicle inspection stations in Poland.

Keywords: VIS, opening of a vehicle inspection station.

Category of the paper: Research paper.

1. Introduction

In developed countries, road safety is considered a fundamental component of transport policy, given its direct impact on the quality of life of citizens and the efficiency of the economy. The objective of contemporary societies is to minimise the number of road accidents and their deleterious consequences. The level of road traffic safety is contingent on a number of factors, including the quality of road infrastructure, the behaviour of road users, the effectiveness of surveillance systems, and, albeit less frequently recognised, the technical condition of vehicles on the roads. In this regard, vehicle inspection stations (VIS) assume a pivotal function, as they are entrusted with the responsibility of conducting compulsory technical inspections within Poland. Vehicle inspection stations represent a pivotal component within the overarching framework of the logistical supply chain, as they serve to guarantee the technical integrity and safety of vehicles employed in the transportation of individuals and goods (Bakje, Karpiński, 2015). In accordance with prevailing legislation, motor vehicles are required to undergo a series of technical inspections at designated intervals, facilitating the timely identification of defects that could compromise safety for road users (Art. 81 Road Traffic Act, 1997). A pivotal element of the VIS's operations pertains to the aggregation and examination of data concerning the technical status of vehicles, a process that is instrumental in the effective oversight of the transport fleet and the implementation of its preventative maintenance measures. The data obtained during technical inspections assists transport operators in planning maintenance activities, thereby ensuring enhanced fleet reliability and reduced risk of breakdowns during operation. The regular undertaking of technical inspections facilitates the identification of irregularities prior to the occurrence of breakdowns, a process of paramount importance within the transport sector, where the assurance of uninterrupted service and safety is of the essence. Moreover, as a consequence of these inspections, defects that may compromise safety can be identified early on, and transport efficiency can be enhanced, thereby contributing to a reduction in long-term transport costs. The necessity for VIS to provide continuous staff training is imposed by technical and certification requirements, which are important for the continuity and quality of logistics services (Kuranc et al., 2014). The collaboration of VIS with supervisory authorities, such as the Transport Technical Supervision TDT and GITD, serves to ensure the maintenance of safety standards, thereby enhancing the reliability of road transport. The evaluation of the technical condition of vehicles has been demonstrated to influence the sustainability of transport by controlling exhaust emissions and wear and tear on consumables. In the contemporary context of mounting concern for climate change and sustainability, the management of exhaust emissions assumes paramount importance, as older or inadequately maintained vehicles have been shown to generate markedly elevated levels of air pollution. The regular maintenance of these vehicles is instrumental in ensuring their effective removal from circulation, thereby exerting a favourable influence on the quality of the atmosphere, particularly within urban areas (Melas et al., 2021).

In the context of ensuring road safety, effective information flow, and the efficient transport of people and goods from point A to point B, the prompt launch of a Vehicle Inspection Station (SKP) becomes extremely important. Efficiently operating SKPs are a vital element of the country's logistical infrastructure, as they enable ongoing assessment of the technical condition of vehicles participating in road traffic, which directly impacts the fluidity and safety of the entire transportation system. With the growing number of registered vehicles in Poland in recent years, there has also been an increased demand for diagnostic services (GUS, 2025). Therefore, it can be expected that the number of vehicle inspection stations will steadily increase, and the efficiency of the processes related to their launch will become crucial for maintaining a functional and safe transport system. The article includes an introduction, a literature review presenting the significance of vehicle inspection stations in the context of logistics, transport safety, and process management, as well as a case study on the launch of a District Vehicle Inspection Station in the Mikołów, including a detailed analysis of the stages, disruptions, and recommendations for entrepreneurs. The article concludes with a summary presenting practical and logistical conclusions drawn from the study. The article attempts to answer the following research questions: What are the key stages of the logistical process related to the reactivation of a vehicle inspection station in Poland? And what logistical problems and disruptions may occur during the reactivation of an inactive vehicle inspection station?

2. Literature review

2.1. Importance of vehicle inspection stations for transport and logistics

It is evident that the ongoing surge in the prevalence of road transportation is largely attributable to the advancement of urban centres and their associated infrastructure. The potential for exploration into previously inaccessible regions is increasing (Krysiuk et al., 2015). Research conducted in Germany demonstrates that approximately 80% of all transport undertaken in urban areas is facilitated by road transport (Kijewska, Iwan, 2011). Vehicle inspection stations (VISs) are instrumental in ensuring the safety and efficiency of road transport, constituting the cornerstone of the vehicle technical inspection system. A basic VIS is an establishment that has been authorised to carry out periodic and additional technical inspections of light vehicles. The term 'light vehicles' refers to cars, motorbikes, light vans and trailers with a maximum weight of 3.5 tonnes. The scope of inspection encompasses a range of vehicle components and systems, including braking, steering, suspension, lighting, exhaust emissions, and the condition of tyres and number plates (Napierała, 2021). In accordance with the stipulated formal requirements, such a station is required to be equipped with the necessary technical apparatus, including measuring devices, a gas detector and an exhaust gas analyser.

Furthermore, the personnel at such stations are obligated to undergo periodic training in order to ensure the proper utilisation of the equipment and the accuracy of the measurements taken (Kuranc et al., 2014). The district VIS is responsible for a significantly broader range of tasks. It conducts all technical inspections, encompassing heavy vehicles, buses, tractor units, specialised vehicles, historic vehicles, and those following accidents or conversions.

The regular undertaking of technical examinations by VIS is instrumental in the identification and eradication of defects that have the potential to compromise road safety. In the context of goods and passenger transport, their role is of particular importance, given that transport vehicles are exposed to intensive use, which increases the risk of breakdowns. Furthermore, VISs facilitate the maintenance of the fleet in optimal technical condition, a pivotal aspect for transport organisations that must ensure the uninterrupted functioning of logistics operations. It was demonstrated (Łukasik, 2016) that adequate technical diagnostics at the VIS can prevent serious vehicle breakdowns during use, which can lead to delays, road accidents or even disasters. It is important to note that the systematic monitoring of the technical condition of vehicles by specialised workshops performing seasonal maintenance (inspections more frequent than those enforced by regulations) is not insignificant for road safety. However, given that this is not compulsory, few users, especially those with older vehicles, i.e. more than 10 years old, opt for such preventive technical inspections. As a vehicle ages, the probability of a malfunction occurring increases (Jarosinski, 2014).

Vehicle inspection stations have been shown to have a significant impact on the reduction of fleet maintenance costs. This is due to the fact that they enable problems to be detected at an early stage, and subsequently rectified with ease. Moreover, the implementation of regular inspection procedures has been demonstrated to mitigate the likelihood of necessitating costly emergency repairs, a pivotal consideration for transport companies. In addition to their primary function, VISs are equipped with the capability to monitor exhaust emissions, thereby enhancing air quality and adhering to environmental standards. This aligns with the principles of sustainable transport policies, contributing to the promotion of environmentally responsible mobility. In the context of public transport development, the presence of these stations has been demonstrated to contribute to passenger comfort and safety by ensuring that buses or trams meet the requisite technical requirements.

By cooperating with technical supervision authorities such as the Transport Technical Supervision (TDT) and the General Inspectorate of Road Transport (GITD), VISs are able to maintain high safety standards. In addition, from an international perspective, the regular undertaking of technical inspections of vehicles is instrumental in ensuring adherence to EU standards, thereby facilitating cross-border transport (Kulakowska, 2013). The utilisation of contemporary diagnostic technologies by contemporary VISs has resulted in enhanced precision and expediency in their inspection procedures, thereby optimising service efficiency. Consequently, within the logistics sector, vehicle inspection stations have been shown to contribute to the optimisation of transport costs, thereby improving the quality of transport

services. From an urban perspective, the organisation and efficiency of transport systems has been demonstrated to have a number of benefits. These include the mitigation of road congestion, the optimisation of network capacity, and the impact on air quality, greenhouse gas emissions, climate change, public health, and the environment (Bastiaanssen et al., 2021).

2.2. Start-up of vehicle inspection stations as a logistical process

In the contemporary business landscape, there is an observable trend of organisations realigning their objectives to prioritise the delivery of products and services that are aligned with the needs and expectations of customers. Consequently, there has been a transition from the conventional functional management model to a process-oriented approach. In this view, an enterprise is regarded as an open system, comprising interrelated processes and elements, the primary function of which is to create value for the customer (Pacholski, Cempel, Pawlewski, 2009, p. 30). A process can be defined as 'a sequential order of activities, starting with the acquisition and processing of information and material resources, which after processing become resources for subsequent sequences of activities performed by internal customers' (Nowosielski, 2008, p. 45). In contrast, Blaik offers a distinct definition of a process as 'an integrated, purposeful system or chain of activities, which is both the result of integration and structuring of activities, and the object of integrated management' (Blaik, 2010, p. 155). The primary objective of employing the process approach in management is to ensure the smooth and rapid flow of materials, goods, products and information through the links of the manufacturing process up to the delivery of value to customers (Misztal, 2017).

The establishment of a vehicle inspection station (VIS) is a complex undertaking, which, in the author's opinion, fully fits into the framework of logistics processes. These are understood as a structured set of activities aimed at effectively managing the flow of physical, information and human resources. The process commences with the identification of market requirements and the undertaking of a location analysis, which corresponds to the strategic planning phase in logistics. The subsequent phase entails the procurement of a suitable technical infrastructure that adheres to stringent normative and spatial criteria. This undertaking necessitates collaboration with public administration institutions and regulatory bodies.

A further element of establishing a VIS is to ensure the provision of specialised technical equipment, in accordance with the provisions of the Regulation of the Minister of Infrastructure and the guidelines of the Transport Technical Supervision (TDT). In this context, the focus is on supply logistics, encompassing the selection of suppliers, delivery scheduling and quality control. The logistics process is also subject to consideration of the human resources aspect, i.e. the recruitment, training and certification of diagnostic staff. This corresponds to personnel and competence logistics (Zawadzka, Jakubczak, Paszko).

Information logistics is of pivotal significance in the process under consideration, incorporating the digitalisation of documentation, the implementation of systems for the recording of technical tests, and communication with the central vehicle database.

It is imperative that all activities are meticulously coordinated in terms of both time and space. The seamless integration of these activities is paramount to ensure the timely and compliant initiation of VIS's operational activities. It is important to note that this process is only completed when the relevant permits are obtained and the station is registered in a list maintained by the district authority.

From a logistical perspective, the commissioning of an VIS can be classified as a unique, multi-stage project that necessitates risk management, quality control, and resource allocation. The system incorporates both physical flows (e.g. diagnostic equipment) and information flows (technical documentation, certificates), thereby confirming the complexity of the underlying processes. Moreover, optimising investment costs, reducing lead times and ensuring the continuity and quality of technical services once the station is operational are pivotal logistics objectives in this context. Consequently, the establishment of a VIS can be regarded as a comprehensive logistics process, necessitating the implementation of the principles of project, operational and information logistics, in accordance with the system and process perspective of logistics (cf. Blaik, 2010; Nowosielski, 2008).

The analysis of available scientific literature indicates that the issue of reactivating vehicle inspection stations is either overlooked or only marginally mentioned. Existing publications mainly focus on technical aspects, the equipment of VIS, and their role in the transportation system and road safety. However, there is a lack of detailed studies describing the logistical process involved in reactivating an existing station. This article aims to fill this research gap through a case study and analysis of the practical aspects of such an undertaking. There is also a lack of current, up-to-date scientific literature on the topic of reactivating vehicle inspection stations. Most available sources are from several years ago and do not take into account the current legal, organizational, and technological realities related to the functioning of VIS. Thus, this article responds to the need for an update in knowledge on this subject and brings a fresh perspective on the logistical and managerial aspects of reactivating the operations of a station.

3. Case study – District Vehicle Inspection Station in the Mikołów district

Case study constitutes a qualitative research technique that is extensively utilised in a variety of disciplines, including the social sciences, economics, technology, management and logistics. The primary objective of this approach is to cultivate a profound comprehension and meticulous analysis of a distinct phenomenon, process or organisational unit within a defined context. The utilisation of a case study facilitates the demonstration of the intricacies inherent in the issue under scrutiny, whilst concomitantly enabling the identification of the interconnections between the diverse factors exerting influence upon it (Grzegorzczuk, 2015).

In the domain of logistics and organisational research, this approach facilitates the analysis of specific investment projects, decision-making processes, the implementation of new systems, and the organisation of the supply chain (Wójcik, 2013). The application of this method facilitates a comprehensive examination of the practical aspects of the business, the identification of barriers and success factors, which is of particular importance in infrastructure projects such as the start-up of a vehicle inspection station (VIS).

The present paper employs the case study method to illustrate the practical course of the investment, to identify critical stages, and to assess the compliance of activities with technical and formal requirements. Moreover, it facilitates the identification of optimal practices and avenues for enhancement that would be beneficial for prospective investors.

3.1. Study object

The research for the presented case study focuses on a District Vehicle Inspection Station (DVIS) located in the Mikołów district, Silesia voivodeship. The facility is located approximately 600 metres from the town centre, which provides it with convenient transport access for both individual customers and businesses. The station was originally constructed in 2009 by a private investor and has been in operation for a period of nearly thirteen years, during which time it has conducted technical vehicle inspections in accordance with current legislation. In 2022, the original proprietor elected to terminate operations, a decision that consequently resulted in the facility being placed on temporary hold.

In December 2024, the decision was taken to lease the station to a new operator. The process of completing the administrative and legal formalities, as well as negotiating the terms of the lease agreement, took several months. Finally, in the final days of April 2025, a formal handover of the facility to the new tenant was conducted, and the latter immediately initiated activities to recommence operations at the station. The sequence of events, from the assumption of control of the facility to the execution of remedial and adaptive measures, has been subjected to a meticulous logistical examination in this paper.

The facility is equipped with a full set of diagnostic equipment necessary to carry out technical tests on vehicles in accordance with current standards. According to the provisions stipulated in the agreement, the former proprietor was obligated to undertake a technical inspection of all equipment and to rectify any malfunctions identified, prior to the commencement of the new operating period. It was imperative that cleaning work be carried out both inside and outside the building, due to the fact that the facility had been out of service for a period exceeding two years. These tasks were expeditiously undertaken by the tenant, thus enabling the facility to be prepared for the resumption of diagnostic activities.

3.2. The logistical and administrative process of setting up a vehicle inspection centre in Poland

The initial phase in establishing a vehicle testing station in Poland entails the verification of the operational integrity, documentation, and certification of the various diagnostic pathway equipment. Concurrently, the preparation of the technical facility documentation is initiated. A comprehensive compendium of data pertaining to the requisite equipment and facilities can be ascertained within the regulatory framework stipulated by the Minister of Transport and Construction, which delineates the detailed requirements for stations entrusted with the responsibility of conducting technical inspections of vehicles. In consideration of the fact that the station under review had only recently recommenced its operations, the present proprietor concentrated on the inspection of the control, measuring and technological equipment. In the case of new facilities, due to the strict guidelines for the building, the testing station and the auxiliary area, it is recommended that the project be prepared and implemented by a specialised company. In accordance with the aforementioned regulation, the test and measurement equipment of a basic vehicle inspection station should include at least the following devices and instruments:

- roller or plate device (overrun device) to check the operation of the brakes,
- device for assessing the correct alignment of the vehicle's road wheels,
- instrument for measuring and adjusting the air pressure in the vehicle tyres,
- instrument to measure the alignment and luminosity of a vehicle's headlights,
- instrument for measuring the light transmission coefficient in vehicle windows,
- sound level meter,
- exhaust gas meter,
- instrument for checking the vehicle-trailer electrical connection,
- device for exerting controlled pressure on the overrun brake control mechanism of a trailer,
- device for forcing the vehicle's road wheels to jerk,
- diagnostic information reader for OBD II/EOBD system,
- multi-component exhaust gas analyser for spark-ignition engines,
- retarder to check brake function,
- assembly tool kit,
- basic set of general-purpose measuring instruments.

The district vehicle inspection station should additionally have:

- wheel and axle alignment measuring instrument,
- electronic gas leak detector for checking gas leaks,
- device to check the effectiveness of the suspension damping of a vehicle with a maximum permissible weight of up to 3.5 t,
- set of torque spanners from 20 to 400 Nm.

It is imperative that each of the diagnostic devices included in the equipment of the vehicle inspection station is accompanied by a complete set of technical documentation, encompassing instructions for use and a certificate confirming compliance with the applicable standards. In the absence of an instruction manual, it is necessary to apply to the manufacturer for its re-issue. Furthermore, the absence of a certificate of conformity necessitates the initiation of action to obtain it. This can be done either by obtaining it directly from the manufacturer or, in cases where there is justification, through the Office of Technical Inspection. In the case in question, all diagnostic equipment remained fully operational and had complete, up-to-date technical and operational documentation, meeting the formal and technical requirements set by the institutions supervising the commissioning of the station.

The subsequent stage of the process is to prepare and submit an application for the issuance of a certificate of conformity for the equipment and premises of the VIS with the requirements, respectively, to the scope of tests to be carried out to the Transport Technical Supervision. The official website of the Transport Technical Supervision provides access to a template of the application. The application contains detailed information on the technical equipment of the facility, including the names of manufacturers of individual devices, their serial numbers and certificate numbers. It is therefore imperative that all documents are prepared in advance. The application, upon completion, should be submitted in its original form to the office of the Transport Technical Supervision. The application may be dispatched via post to the address aforementioned, or alternatively submitted electronically via email. It is also possible to submit the application at a TDT branch office. However, it should be noted that when submitting an application in electronic form, it is imperative that it is signed with a qualified signature. In the event of errors being detected in the application, it will be returned with a request to remedy the identified deficiency or to correct the data contained therein. In the case in question, the application was submitted online and returned on two occasions. The initial instance pertained to the absence of a signature on the document, as it contained solely a handwritten signature and lacked an electronic signature. The subsequent instance concerned the absence of a postal code. Following a thorough evaluation, the application was ultimately approved. Subsequent to the submission of the requisite documentation, the proprietor was contacted by an inspector, who scheduled an inspection of the station.

The third stage of the process of resuming the operation of a district vehicle inspection station is the inspection of the station by the TDT inspector. The following documentation must be prepared for the inspection:

- lease, rental agreement or title deed,
- structural and construction design of the building and the inspection pit in the original version,
- instructions and certificates for control and measurement devices and process equipment,
- information on the assessment criteria for the vehicles tested,

- applicable legislation setting out the requirements for the technical conditions and technical tests of vehicles, in accordance with the scope of the tests carried out by the station, including:
 - Act of 20 June 1997 - Road Traffic Law,
 - Act of 21 April 2005 amending the Act on Value Added Tax and amending certain other acts (Journal of Laws No. 90, item 756),
 - Printed regulations on:
 - technical conditions for vehicles and the scope of their necessary equipment,
 - level of fees relating to the operation of vehicle testing stations and the carrying out of technical inspections of vehicles,
 - scope and manner of carrying out technical tests of vehicles and the specimens of documents used for these tests,
 - detailed manner and procedure for assigning and fitting identification features to vehicles,
 - testing the conformity of historic and SAM vehicles with technical conditions,
 - European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR), done at Geneva on 30 September 1957, including annexes,
- a copy of the decision on the permission to use the building.

When inspecting a vehicle inspection station (VIS), an inspector of the Transport Technical Supervision (TDT) carries out a comprehensive assessment of the facility's compliance with the applicable technical and organisational regulations. He/she first verifies the technical documentation of the station, including the design of the facility, declarations of conformity of equipment and CE certificates. Next, he/she assesses the technical equipment, checking the presence, technical condition and completeness of measuring equipment in accordance with the requirements of the Regulation of the Minister of Infrastructure. The inspector checks the arrangement of the equipment at the diagnostic station and its adaptation to the tests foreseen for a given category of VIS. He/she also checks the lighting, ventilation and labelling of the stands, which must comply with health and safety standards and technical conditions. Should irregularities be detected, the inspector may issue post-inspection recommendations or suspend the operation of the station. The inspection is concluded with the formulation of a protocol, which establishes the foundation for subsequent administrative measures. In the case under consideration, an inspection conducted by an inspector of the Transport Technical Supervision revealed that the documentation did not contain any information regarding the permissible overloading of the inspection pit flange by 25% above its nominal load capacity. Consequently, a post-inspection recommendation was issued, stipulating that the station owner must furnish the missing technical data. Following the submission of the requisite documentation, which delineated the allowable overload parameters of the structure, the owner was granted a positive formal verification. Finally, the Transport Technical Supervision

Department issued a document via post, thereby confirming that the facility met the requisite technical and formal requirements. This permitted the subsequent commissioning of the station.

The next stage is to submit an application for entry in the register of entrepreneurs operating vehicle inspection stations (VISs) to the Mikołów District Office. This stage begins with the preparation of a set of required documents. The entrepreneur must submit an application for entry containing company data, the address of the VIS and the scope of the planned technical tests. The application must be accompanied by a certificate of compliance with the technical requirements issued by the Transport Technical Supervision (TDT). Copies of the qualifications of the diagnosticians who will perform technical tests at the station are also required. Documents confirming the right to dispose of the premises (e.g. title deed or lease agreement) and confirmation of entry in CEIDG or KRS must also be attached. The application may be submitted in person at the Department of Transport of the District Starost Office in Mikołów, or alternatively it may be dispatched via post. The responsibility for formal and content-related verification of the documentation is that of officials. Following a favourable evaluation, the entrepreneur is formally registered with the VIS and is subsequently permitted to commence commercial activities. The process culminates in the issuance of a certificate of entry, a document which is requisite for the lawful operation of the station, and the allocation of the station number.

Stage 5 of the process involves the submission of an application to the CEPiK system, otherwise known as the Central Register of Vehicles and Drivers. This stage requires the submission of two separate applications: the first is for a card system operator, and the second is for devices (VPN, PKCS 12). A system operator, i.e. an individual who operates a device with access to CEPiK (e.g. a diagnostician), is required to submit an application for an access card (the so-called cryptographic card) to the Central Informatics Centre (CIC). It is evident that the application under scrutiny contains personal data, personal ID No. data and VIS data, in which the work is to be performed. It is imperative that this application be submitted in either an electronic or a hard-copy format. The address to which submissions should be addressed is indicated within the application itself. Concurrently, the VIS proprietor is obliged to submit an application to CEPiK for equipment (VPN and PKCS12 certificate). It is a mandatory procedure for any vehicle inspection station (VIS) that wishes to transmit data from technical tests to the central register. The application is submitted by the owner of the VIS or an authorised representative and aims to gain access to the CEPiK production environment via a secured VPN connection and an authentication certificate (PKCS#12). The initial step in the process entails the download of the application form from the website of the Central Informatics Centre (CIC), followed by its completion. In the application form, the following details are to be provided: the VIS's identification details, its location, region number and the contact details of the technical administrator. This step is necessary because each station and each diagnostician must have active CEPiK privileges in order to legally perform technical tests and send their results to the central register. It is not possible to submit applications that bypass the preceding stages,

as these require the station number that is assigned by the Starost's office after entry in the register of entrepreneurs running a vehicle inspection station.

The subsequent stage is to procure the software that facilitates the operation of the diagnostic station and to establish a connection with CEPiK. Examples of software include: SKP PRO, SKP-KOMET, MotoSoft SKP, ProSKP and Auto-Stacja. It is noteworthy that all of these programmes are CEPiK 2.0 compliant, a feature which facilitates the electronic transmission of technical inspection data. The software in question has been developed for the purpose of supporting diagnosticians' cryptographic cards and PKCS#12 certificates, in addition to integrating with diagnostic equipment. The organisation also provides archiving of documentation, report generation and a user-friendly interface adapted to the work of VIS.

In the case under review, the SKP PRO software was selected on the basis of the owner's prior positive experience with its use. It is recommended that the TeamViewer programme be installed. This is a software solution employed by CEPiK technical support to remotely configure the connection with the central system. The process under discussion does not necessitate the utilisation of sophisticated IT expertise on the part of the proprietor. The proprietor's involvement is confined to the provision of passwords and a segment of the installation code stipulated in the application for the purpose of establishing a connection to CEPiK. Following the establishment of a connection with the central system, the selected software should be installed and linked with the CEPiK certificates received. This process enables the vehicle inspection station to commence formal operation.

The final stage in the process of establishing a District Vehicle Inspection Station is to provision the facility with the equipment necessary to manage payments. In order to comply with current tax legislation, it is necessary to purchase a fiscal cash register and to order a payment terminal from a banking institution that is authorised to handle non-cash transactions. From a legal standpoint, both elements are considered obligatory in the context of providing services to individual and institutional customers.

Following the fulfillment of all technical, formal and organisational requirements, the investigated District Vehicle Inspection Station, located in the Mikołów district, was officially inaugurated on 9 June 2025, thereby resuming operations after a period of more than two years of downtime. The sequence of events that must be followed in order to recommence operations at the District Vehicle Inspection Station is illustrated in Figure 1.

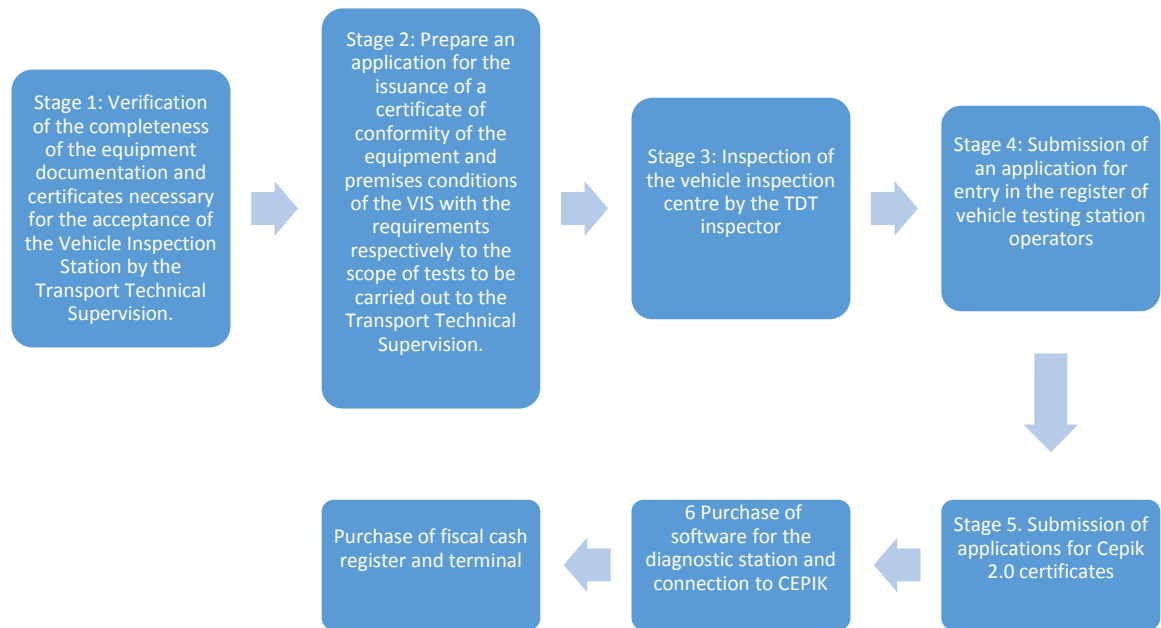


Figure 1. The process of resuming the operation of vehicle inspection stations.

Source: Own study based on conducted research.

3.3. Disruption during the process

The following distortions were identified during the commissioning process of the District Vehicle Inspection Station, which was analysed:

- It was observed that there were deficiencies in the technical documentation of the diagnostic equipment. While the majority of the documentation was found to be complete, the TDT inspector reported a lack of confirmation regarding the permissible overloading of the inspection pit. This resulted in post-inspection recommendations being made, which in turn led to a delay in the acceptance procedure.
- Administrative delays - the process of leasing, paperwork with TDT, obtaining certificates and applying for CEPiK connection may have encountered delays beyond the owner's control.
- Despite the software being compatible, configuration errors and hardware incompatibility have been proven to be problematic, resulting in the reinstallation of certificates.
- Problems with the installation of the diagnostic software, which resulted from the lack of installation instructions.
- Delays in the delivery of a payment terminal or fiscal cash register - dependent on lead times from suppliers, which also affected the start date.
- Staffing problems - the entrepreneur encountered difficulties in recruiting qualified diagnosticians who met the formal requirements, which made it impossible to start the business.

- It was determined that the fabrication of the stamps and the information board should be initiated at an earlier stage. During the process analysis, it was also established that a disruption occurred in relation to the premature production of the station identification elements. The proprietor elected to manufacture the stamps and procure the information board prior to the formal allocation of the station number by the designated district office. It was erroneously hypothesised that the station identification number would remain unchanged since the temporary closure. However, administrative procedures resulted in the assignment of a new number, necessitating the redaction of both the stamps and the information board. This error resulted in unanticipated expenditures and a delay in the commencement of station operations. This underscores the significance of adhering to the prescribed sequence of administrative actions in the logistical process of initiating a VIS.

3.4. Recommendations for entrepreneurs

The establishment of a Vehicle Inspection Station (VIS) is a process that is characterised by numerous challenges that must be given full consideration by entrepreneurs at every stage of the process. In order to ensure both smoothness and compliance with current regulations, it is first necessary to conduct a thorough formal and legal analysis. Prior to initiation of the process, it is imperative to ensure that all requirements, documents and procedures are thoroughly comprehended and meticulously planned.

It is also imperative to adhere to the stipulated administrative sequence. It is imperative that the proprietor of the station does not initiate the procurement of stamps, information boards or promotional materials for the station until the station number has been received from the District Office. Prior to the submission of the station for acceptance by the Transport Technical Supervision (TST), particular attention must be paid to the thoroughness of the technical documentation of the diagnostic equipment. It is imperative that each piece of equipment utilised at the station is accompanied by an operating manual that is current, a certificate of inspection, and the requisite approval for its utilisation. Without these documents, the acceptance process will be unable to proceed, which may result in delays to the commencement of operations.

It is imperative to give due consideration to the issue of technical downtime, particularly in instances where the station has been inoperative for a considerable duration. The necessity for equipment to be overhauled, calibrated or repaired can incur additional costs and require a significant time investment. It is also considered good practice to make financial provisions for unforeseen expenses that may arise during the preparatory phase for operation of the station.

The selection of appropriate software is a pivotal factor in determining the efficiency and compatibility of the station with the CEPiK system. It is incumbent upon entrepreneurs to ensure that the selected software is compatible with the requirements of the CEPiK 2.0 system,

supports the required certificates and provides technical support. This will ensure that the process of transferring technical test data to the CEPiK system is smooth and uninterrupted.

Furthermore, it is recommended that the opening of the station is planned with sufficient time allowance. It is important to note that administrative processes, technical acceptance or registration in state systems can often be subject to delays. Therefore, it is advisable to allocate sufficient time for potential delays that may be incurred due to equipment deliveries or procedures at government offices.

Finally, entrepreneurs are advised to ensure that each stage of the station start-up process is meticulously documented. It is important to note that, if the relevant documentation is completed meticulously at the outset, the subsequent process of undergoing inspections, audits or appeal procedures will be less onerous. This approach has been shown to minimise the risk of errors and increase the transparency of the process.

Adherence to these recommendations is instrumental in ensuring the seamless establishment of Vehicle Inspection Stations, thereby mitigating the risk of disruption, delays, and superfluous expenditures.

4. Summary

The establishment of a District Vehicle Inspection Station (DVIS) is a complex logistical process, necessitating meticulous management of the individual stages. These include the preparation of documentation, ensuring compliance with standards, and the implementation of technology to support the service of technical tests. The entire process is inextricably linked to logistics, as it encompasses the movement of material resources (e.g. diagnostic equipment, software, documentation) and information resources (e.g. vehicle data, test results, certificates). A logistical approach to the launch of an inspection station involves the management of the entire chain of activities, starting with an analysis of the technical condition of diagnostic equipment, through its certification, up to the integration of computer systems with the central system for vehicle records - CEPiK 2.0. In this context, the organisation and coordination of activities such as the selection of appropriate software, the implementation of payment systems or the management of documentation are fundamental to ensure the smooth launch of the station and its subsequent efficient operation.

The management of the process of launching an VIS is therefore of paramount importance from the perspective of optimising logistical activities, which must follow a strict sequence. Entrepreneurs contemplating the establishment of such a station are obligated to consider a number of formalities, ranging from the procurement of requisite authorisations and certifications for diagnostic equipment, to the meticulous organisation of the integration process into the state system, to the assurance of adequate tools for the management of the customer

service process. As is the case in any logistical process, it is imperative to minimise the risk of delays and disruptions. Such delays and disruptions may take the form of administrative errors (e.g. misplaced stamps that require correction), documentation problems or software configuration errors.

Moreover, the establishment of Vehicle Inspection Stations is of paramount importance from the perspective of road safety, which is recognised as one of the fundamental cornerstones of transport policy in developed countries. The management of the diagnostic process in the context of VIS also has an impact on the ecology and sustainability of transport. The evaluation of the technical condition of vehicles encompasses the analysis of exhaust emissions, a pivotal consideration in the context of mitigating the adverse environmental impact of transport.

The launch of the District Vehicle Inspection Station in Poland required the completion of many administrative and technical formalities. It was necessary to prepare the appropriate equipment, submit an application to the Transport Technical Supervision (TDT), and register with the Central Vehicle and Driver Registration (CEPiK). The process concerned a station that, after several years of inactivity, was to resume operations, which required the updating of documentation. During the inspection by the TDT inspector, the absence of required technical information was discovered, which delayed the entire process. After the irregularities were addressed and the TDT issued a positive decision, it was possible to submit the documents to the District Office and begin the next steps. The station also had to install and test computer systems for customer service and communication with CEPiK. Additionally, a payment terminal was purchased, and necessary contracts with service providers were signed. Despite numerous organizational challenges, the station was eventually launched on June 9, 2025.

To summarise, the initiation of a District Vehicle Inspection Station is a complex logistical process that necessitates meticulous management of material resources, information, and adherence to prevailing legal regulations. The efficient management of this process is pivotal in ensuring the operational efficiency of the station, whilst concurrently contributing to road safety and environmental protection. It is incumbent upon entrepreneurs planning to establish such a station to adhere to robust logistical practices in order to mitigate the risk of delays and errors, and to ensure the quality of the diagnostic services provided.

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