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TECHNOLOGY ASSESSMENT IN THE FIELD OF TRANSPORT AND LOGISTICS IN THE SILESIAN VOIVODSHIP

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Purpose: In the contemporary era, metropolitan areas and regions are confronted with a plethora of challenges in the realm of transportation and logistics management. This assertion is substantiated by a variety of technological solutions that facilitate the streamlining of processes, the mitigation of the deleterious environmental impact of these activities, and the enhancement of people's living standards. These technologies have been extensively discussed in the literature; however, their analysis within the context of specific regions remains underdeveloped. Due to this fact, the aim of the article was to provide recommendations for identified technologies in the area of transport and logistics in the Silesian Voivodeship.
Design/methodology/approach: The paper assesses 18 technologies in the area of transport and logistics in the Silesia Voivodeship, assigning them to four categories. The assessment was based on three criteria: the effectiveness of the technologies, the market age of the technologies, and their impact on the technological landscape. The analyses employed an expert survey, incorporating a technology assessment questionnaire.
Findings: The analyses identified six sets of technologies in the area of transport and logistics in the Silesia Voivodeship, differentiated in terms of their importance and level of use and further development. Recommendations were provided for each identified set of technologies.
Research limitations/implications: The research is concentrated within one voivodeship. The subsequent expansion of these enterprises into other regions and countries represents a promising avenue for further research. Furthermore, subsequent research endeavours will seek to refine the focus of the technologies under scrutiny.
Originality/value: Application of a technology appraisal methodology in the field of transport and logistics for the Silesian Voivodeship.
Keywords: transport and logistics, technology assessment, storage technologies, information technologies, transport technologies.
Category of the paper: research paper.

1. Introduction

Cities can't function without well-organized transport and logistics processes (Kauf, 2016a). These processes are related to the implementation of cargo, people, energy, and accompanying information flows within the city's logistics system while maintaining the assumed goals, including minimizing flow costs and improving the quality of life in the city (Jefimowaitė, Vienažindienė, 2022; Płaczek, 2011). At the same time, trends such as urbanization, changes in human behavior (e.g., increased mobility, development of e-commerce sales), and rising expectations regarding the quality of life are making transport and logistics aspects a major problem in cities and regions around the world (Alarcón et al., 2023; Kauf, 2016b). Unfortunately, these processes, in addition to their basic and necessary role, also generate a number of negative effects related to environmental pollution (air, soil, water), noise, increased congestion, accidents, infrastructure occupancy, and social exclusion (Mężyk, Zamkowska, 2016; Szołtysek, Twaróg, 2012). Therefore, the challenge for logistics is to minimize the identified problems and shape flows consistent with the concept of sustainable development, which assumes the harmonious development of regional social, economic, and environmental conditions, contributing to improved quality of life in the indefinite future (Sobol, 2017).

In response to constant changes, new societal needs, and emerging problems and challenges, support for transport and logistics activities through various solutions that improve the functioning of cities is becoming increasingly important (Bondar et al., 2022). Consequently, there is a growing global demand for new, often innovative, technologies in the field of city logistics (Winkowska et al., 2019; Szpilko et al., 2020; Dąbrowska et al., 2023). The concept of technology is broad and ambiguous in the extant literature. Its multifaceted nature is evident in its perception through various lenses, including machines, equipment, tools, materials, and products, collectively termed 'artefacts'. Additionally, it is interpreted through the lens of science and knowledge in its broadest sense, encompassing know-how, patents, tacit knowledge, and skills. Furthermore, techniques and methods, along with activities and processes, are intricately woven into the fabric of production methods (Bielińska-Dudzic in 2020). The term 'technology' itself is derived from the Greek 'technology', signifying the systematic treatment of an art or craft. One of the more fundamental definitions is that proposed by Dosi et al. (1990), which states that technology constitutes a collection of elements of practical and theoretical knowledge, the ability to apply it (i.e. know-how), methods, procedures and physical devices that utilise this knowledge. There is a widespread consensus among both management theorists and practitioners regarding the role of technology. Changes resulting from the technological race are becoming commonplace, even necessary. Consequently, the choice of technology, the timing of its introduction or withdrawal, are becoming key issues in technology management, and even management in general (Chyba, 2016). Awareness of the need for technology development has become widespread, as evidenced by international and national programs supporting technology development and the activities of scientific research and development institutions. Given the growing demand for innovative technologies and the developed technology market, technology analysis and assessment seem essential. Their goals include characterizing and examining the technologies in use, determining their potential, and defining directions for development. Technology analysis and assessment enable the identification of strengths and weaknesses of technological activities, identifying opportunities for increasing competitive advantage through appropriate technology use, and identifying available technologies that could be applied to improve processes (Halicka, 2016).

In contemporary urban and regional contexts, a diverse array of technologies is employed for the management of freight, human mobility, and the dissemination of information. However, it is important to note that the level of support for technologies varies across different cities and regions. The technologies employed, the extent of their implementation, and the trajectories of their evolution are subject to variation. Therefore, in reference to the presented research problem, the aim of the article is to provide recommendations for identified technologies in the area of transport and logistics in the Silesian Voivodeship. The present study adopted three research questions in relation to the formulated aim of the paper:

1. What is the set of technologies used in the area of transport and logistics in urban and regional transport and logistics systems?
2. How to assess technologies in the area of transport and logistics in cities and regions?
3. What is the level of development of technologies in the field of transport and logistics in the Silesia Voivodeship?

It is important to note that the majority of research on technology assessment methods is of a universal nature, whereas the analyses conducted for the Silesian Province serve as a case study. The selection of the province for analysis is dictated by the research conducted by the authors as part of the Translog Transport and Logistics Observatory established in the Silesian Province. The observatory was established as part of the network of Regional Specialised Observatories in the Process of Entrepreneurial Discovery (SO RIS in PPO). The primary objective of the Observatory is to monitor global trends in urban logistics and to combine expert knowledge in order to improve it in the Silesian Province. It is evident that the research problem addressed in this paper is congruent with the tasks that have been undertaken by the Observatory.

In order to achieve the objective and answer the research questions, a literature review was conducted, focusing on the identification of technologies supporting transport and logistics in urban and regional systems. This is outlined in section 2 of the paper. The subsequent section will address the methodology of the research. Its use allowed us to obtain research results on technology assessment in the Silesian Voivodeship. These results were used to formulate recommendations. These findings are elucidated in Section 4, entitled "Results and Discussion". The paper concludes with a series of final conclusions.

2. Technologies in the field of transport and logistics – theoretical background

The flows realised in urban and regional transport and logistics systems involve different flows, the main ones being material goods (raw materials, materials, semi-finished products, spare parts, finished products), people and information. These flows necessitate the utilisation of technologies that facilitate their realisation and concurrently provide support, thereby enhancing efficiency, effectiveness, and stakeholder satisfaction.

The main subsystem requiring technology support is freight transport, which, by virtue of its complementary nature, constitutes the basis of all economic activity. The responsibility attributed to the concept of regional development is twofold: firstly, in terms of the development of individual economic branches, and secondly, in terms of the development of regions. Consequently, it is imperative to direct attention towards technological advancements that will facilitate the establishment of a contemporary and pioneering transportation system that is both environmentally sustainable and socially inclusive. It is evident that a number of the technologies are associated with multi- and intermodal transport. This perspective is consistent with the assertions made in strategic documents that underscore the significance of these modes of transportation. For instance, the White Paper (Transport Commission, 2011) and the Strategy for Sustainable Transport Development to 2030 (2019). The evolution of multi-modal and intermodal transportation has enabled the integration of transport policy assumptions with the principles of sustainable development. This integration has facilitated the development of eco-friendly transportation solutions that are less energy-intensive and generate lower external costs. The foundation for intermodal transportation is the establishment of contemporary solutions for the transhipment of intermodal loading units (containers, swap bodies, semi-trailers, or bimodal trailers), encompassing both vertical (lo-lo) and horizontal (ro-ro) transhipment technologies. A notable example of this is Modalohr. The implementation of these and other solutions pertaining to inter-branch transshipment is contingent upon the integration of technologies that are underpinned by novel advancements in the domain of rail wagons, road transport modalities, and infrastructure at transshipment terminals. The field of freight transport is heavily reliant on contemporary technologies, which have facilitated the development of various means of transport and loading facilities across different modes. Other technologies of particular importance include those related to autonomous vehicles and drones. There is a general trend related to the significant interest in these types of solutions due to their innovation, reduced human resource commitment and their relationship to 'last mile' transport. In particular, the use of electric and low-emission vans, freight trams, delivery bicycles, and other vehicles powered by alternative propulsion sources has attracted significant attention in recent research (see Taniguchi et al., 2014; Bellandi et al., 2014; Iwan et al., 2018; Kauf, 2016b; Taniguchi et al., 2020). A significant challenge in the domain of freight transport pertains to the delivery of parcels, a phenomenon concomitant with the rapid expansion of e-commerce. This issue is further compounded by the intricate dynamics of 'last mile' transport flows. In such circumstances, both logistics companies and city and regional managers face a considerable challenge in organising sustainable parcel flows (Heitz, Beziat, 2016; Montwiłł et al., 2021; Nathnail et al., 2016). Examples include the development of alternative delivery and collection points based on locations other than the customer's home (e.g. a shop or gas station) (Vural, Aktepe, 2022); and the development of parcel vending machines (Taniguchi et al., Recent studies have explored the potential of drones in the context of parcel delivery (Müller et al., 2019), the development of urban and regional consolidation or distribution centres (Taniguchi et al., 2020; Pan et al., 2015; Serafini et al., 2018; Chen, Pan, 2015), the utilisation of alternative modes of transport (e.g. delivery bicycles) (Pan et al., 2015), and the development of the concept of crowdshipping (based on the idea of crowdsourcing, which involves the use of so-called crowd potential) (Taniguchi et al., 2020; Serafini et al., 2018).

The domain of passenger transport is another area that necessitates the integration and implementation of contemporary technologies for both individual and collective transportation. The utilisation of public collective transport is identified as a significant factor in reducing road transport and, consequently, reducing external transport costs and balancing passenger flows. It is asserted that a number of solutions are poised to contribute to this phenomenon, including, but not limited to, the implementation of a city card system (Grad et al., 2013; Jaroszyński, Chłąd, 2015), the establishment of a dynamic (real) passenger information system (Grad et al., 2013; Kiba-Janiak, 2012), and the introduction of dedicated bus lanes, along with the incorporation of smaller buses that operate at a higher frequency than standard buses (Kiba-Janiak, 2012). In the pursuit of diminishing the prevalence of road transport modes, alternative solutions have been proposed. These include the facilitation of multimodal travel through the implementation of micromobility options, such as urban bicycle and scooter systems, as well as the promotion of car-sharing and car-pooling initiatives. Additionally, the introduction of incentives to encourage the utilisation of public transportation has been mooted (Kiba-Janiak, 2012; Szołtysek, 2016; Jaroszyński, Chłąd, 2015). The primary focus is on the development and enhancement of railway infrastructure, including both linear and point-based facilities, which serve as a robust alternative to road transportation. Additionally, there is a strong impetus to transition to more environmentally sustainable rolling stock, such as electric vehicles or hydrogen-powered buses. Concurrently, there is a necessity to develop infrastructure dedicated to these types of vehicles, including car parks, repair points and charging stations (Iwan et al., 2018). A significant amount of attention has been dedicated to autonomous vehicles and their utilisation in passenger transportation, emphasising the potential environmental, societal and economic benefits. These benefits encompass enhanced safety, reduced congestion and optimised traffic flow, as well as augmented mobility for individuals with disabilities or for the elderly (Future Industry Platform, 2025). Furthermore, the introduction of multi-level and collision-free intersections and traffic lights to regulate traffic, thereby enhancing transport safety, as well as the construction of underground or multi-storey car parks, are proposed as effective solutions (Stawasz, 2015). The development of collective public transport, both rail and road, as well as the aforementioned micromobility, additionally requires the construction of sites that will allow multimodality of travel. As posited by (Cichosz, 2015; Bul, 2017; Kauf, 2012), the following measures are primarily recommended: the construction of interchanges, the creation of infrastructure that facilitates the combination of cycling with public transport (e.g. B&R), and the establishment of infrastructure that enables the integration of trips by private vehicles with public transport (e.g. P&R).

The implementation of transport and logistics processes is widely supported by developed information technologies. Of particular note is the Internet of Things (IoT), a term defined as a modular method of integrating various sensors with all information and communication technologies (Blicharz, 2023). Alternatively, the IoT can be viewed as a totality of smart objects that can respond to the environment and process information, subsequently relaying it to other objects and users (Rot, 2017). A fundamental function of the Internet of Things (IoT) is the aggregation of data from multiple sources and the management of critical resources, including water, energy, transportation, waste, and public safety, to name a few (Balicka, 2023). The utilisation of collected data has the potential to enhance transparency in local government activities, to raise residents' awareness of their city's state, and to stimulate their desire to participate in municipal activities (Baraniewicz-Kotasińska, 2017). In the context of logistics, the Internet of Things (IoT) is being used extensively in the creation of an intelligent transport system, including through smart roads, car parks, bicycle systems, vehicles, street lighting, public transport, and real-time traffic management (Szum, 2021). Its application is also evident in the domain of waste management (Bondar et al., 2023). The utilisation of the Internet of Things (IoT) is evident in the Intelligent Transport Systems (ITS) under development. These technologies encompass a wide range of disciplines, including telecommunications, information technology, automation, and measurement, in addition to management techniques. These are applied to the domain of transport with the objective of safeguarding the lives of traffic participants, enhancing transport efficiency, and protecting environmental resources (Dembińska et al., 2018). ITS are applications that link data collection, communication, data mining, machine learning, artificial intelligence and database management (Tomaszewska, 2022). The objective of these initiatives is to furnish services pertaining to diverse modes of transport and traffic management, thereby enabling varied users to be more informed. Furthermore, these initiatives aspire to facilitate a safer, more coordinated and more intelligent utilisation of transport networks (Wojewódzka-Król, Rolbiecki, 2018). The present moment marks the current vanguard of artificial intelligence in the domain of transport and logistics operations. AI algorithms have the capacity to analyse vast quantities of data, including vehicle location, road condition, weather conditions and demand patterns, thereby determining optimal routes and minimising delivery times. This has been demonstrated to result in fuel savings, reduced CO_2 emissions and enhanced customer service. Furthermore, AI algorithms have the capacity to analyse data from sensors mounted on vehicles and machines, with the objective of predicting and preventing breakdowns before they occur (Envio Group, 2024). The AI technologies utilised are concomitantly associated with a plethora of mobile applications and digital platforms dedicated to residents or property owners (Jąderko et al., 2016), or the creation of an environment for the sharing of resources and the facilitation of customer integration (Strojna et al., 2022). Moreover, the utilisation of information technology, machine learning algorithms and the concept of the Internet of Things (IoT) constitutes the primary foundation for the development of contemporary solutions within the domain of waste logistics (Marques et al., 2019; Lewicki, 2018). The development of transport, both freight and passenger transport, also requires the support of automatic identification systems and data capture techniques (Automatic identification and data capture). The utilisation of automatic identification and data capture technologies facilitates the provision of real-time visibility at the point of shipment, the prediction of delivery times, and the explanation of delayed deliveries and much more (Rusek, Pniewski, 2016).

Warehouses represent a pivotal component within the framework of supply chains. In addition to their traditional function of inventory storage, they have expanded their operations to encompass a range of value-added services, including packaging, wrapping, and co-packing. The broad spectrum of tasks undertaken by warehouses has led to an increased focus on strategies to enhance competitiveness through process optimisation or cost reduction. The predominant trend observed in warehouses pertains to the automation and robotisation of their operations. For instance, in the context of automated high-bay warehouses, stacker cranes are assuming the function previously performed by forklift operators. The rapid and safe movement of loads, along with the optimisation of warehouse space utilisation, has been demonstrated (Grabowy, Wielgosz, 2018). Mobile robots serve as a prime illustration of the integration of robotics within warehouse environments. These devices facilitate the movement of inventory within the warehouse environment, enabling the efficient transportation of storage units between specific locations. Mobile robots can be categorised into two distinct classifications: AMR and AGV (Jardzioch, 2020). AGV technology is predicated on the utilisation of unmanned transport vehicles, which are engineered to convey objects along a designated route (Bednarz, 2018; Surma, 2020). AMR robots can be regarded as a more advanced iteration of AGVs. These devices are equipped with scanners, cameras, and sensors that facilitate the acquisition of comprehensive real-time environmental data. In the possession of such information, the robot is capable of navigating the storage area autonomously and reacting to a changing environment or emerging obstacles (Jardzioch, 2020). Another illustration of this phenomenon is provided by Amazon's experimentation with the utilisation of the Digit humanoid robot in the context of picking processes. The integration of unmanned aerial vehicles, more commonly referred to as drones, into warehouse operations is a recent development. These devices can facilitate hall inspections or warehouse rack surveys, and are also used in inventory management. Their ability to maintain a stationary position in the air affords them a wide field of vision, thus enabling them to facilitate the work of warehouse personnel. This assistance may take the form of indicating safe routes or assisting in the manoeuvring of trolleys in confined spaces. The utilisation of drones in the context of stock taking has been demonstrated to contribute to the elimination of errors, the optimisation of time and financial resources, and the enhancement of safety measures for personnel and stored goods (Mecalux, 2021). In the context of warehouse operations, product picking represents a critical procedural element. In this area, the employment of a range of technologies, including Pick by Light, Pick by Point, Pick by Voice, Pick by Frame, Pick by Watch, and Pick by Vision, has been observed (Wróbel, Zbadyński, 2018). The latter is a particularly innovative technology, augmented by augmented reality (AR) (Rusek, Pniewski, 2017). Robots specialising in packaging, such as FANUC, which is equipped with sensors and vision systems to locate packages, packaged products, and put-away locations, also demonstrate proficiency in the realm of picking. It facilitates the accurate and precise packaging without damage to products (Jardzioch, 2020). In considering warehouse technology, the development of sustainable or green warehouses is a salient consideration, with environmentally friendly solutions assuming particular importance. The utilisation of compressors for heat recovery, light-emitting diodes, air destratification and warehouse automation represent merely a subset of the numerous solutions that yield environmental benefits (Mardeusz, 2021). Green warehouses employ a range of techniques and strategies to minimise waste production and energy consumption, motivated by environmental concerns. These principles are integral to the concept of green logistics, which emphasises the mitigation of the carbon footprint and the effective management of resources (Mecalux, 2022).

3. Methodology

In conducting the research to answer the research questions posed in the Introduction, the authors adopted the research methodology shown in Figure 1. It consists of four main phases.

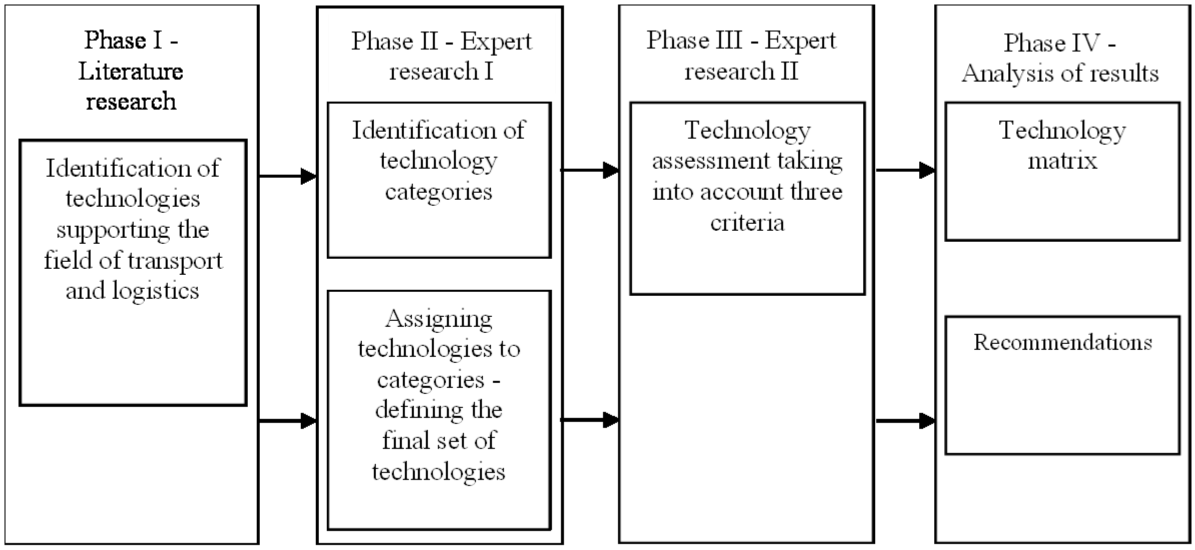

Figure 1. Research methodology.

Source: own work.

In the initial phase of the research, the authors of the study proposed a preliminary list of technologies, based on a thorough literature review. These processes encompassed all aspects of transport and logistics within the systems of cities and regions. In the second stage, a preliminary round of expert research was conducted. The study involved ten experts from both scientific and business practice backgrounds. The research was conducted through a series of interviews and discussions. The objective of the present study was to organise and group the technologies identified during the literature research stage within the adopted categories and to finally validate them. The result of the research conducted at this stage was the preparation of a questionnaire containing a list of technologies organised into four categories. This questionnaire, administered during the third stage of the research, was presented to the experts for their evaluation. Given that the technology assessment pertained to the Silesian Voivodship, the experts were drawn from this specific region. Pursuant to the assumptions that had been made, the technologies were analysed in accordance with the three criteria that are presented in Table 1.

Table 1.
Technology assessment criteria in the field of transport and logistics

Technology assessment criterion	Technology - description
Effectiveness	• base (core) technologies - widely used and available in the sector. Their possession is a necessary, but generally insufficient condition for achieving or maintaining a high competitive position; • key technologies - which are the basis for the competitiveness of the activities carried out; their perfect mastery is a key success factor; • experimental technologies - have little use, are in the early stages of development; they are, however, promising to become key technologies in the future and are therefore also protected from competition.

Cont. table 1.

Market age	• introduction phase - characterised by high uncertainty, research intensity, little application but high development potential. It may be experimental, there may be few or no competitors in the market. The research intensity of the technology is high, aiming to improve the technology and demonstrate its potential benefits; • growth and popularity phase - the technology is characterised by average uncertainty, emphasis on applications, thereby gaining wider acceptance, and demand grows rapidly. The technology is refined and improved and new competitors enter the market. Over time, improved, it can become a key technology, characterised by high efficiency, understood as the ability to reduce costs, create high quality and thus generate profits; • maturity phase - the technology is characterised by low uncertainty, reduced costs and reduced investment; it becomes more standardised and widely used. It has already reached the maximum level of its technological capabilities. The market becomes more saturated and competition more intense. Profits are often lower than in the growth phase; • decline phase - the technology becomes obsolete and is replaced by a new technology with greater competitive value.
Impact on the technological landscape	• niche technology - associated with a narrow, selected area or audience. Has less competition due to a small market of customers; • critical technology - brings an element of innovation with significant potential to the market, or contributes to reducing or preventing strategic dependencies; • disruptive technology - is a new, emerging technology that significantly changes a particular market or industry and, over time, unexpectedly displaces an existing technology. A disruptive technology replaces an established process, product or technology after some time, giving rise to a new way of doing things for consumers or businesses. This can lead to a number of benefits, including lower prices, better service quality and greater competition, and thus revolutionise the industry. In some cases, disruptive technology can even create other markets (e.g. smartphones, which have helped to develop mobile banking); • deep-tech - is characterised by a high degree of uncertainty about their actual technological feasibility at the start of development. As a result, there is a high level of specific R&D efforts up to implementation. There is also a high level of market risk in the early stages of technology development, as the products associated with the technology are very novel and it is often unclear how systems integrators and end customers will react to these adaptations.

Source: compiled from: Chyba, 2016; Halicka, 2016; https://www.focus.pl/artykul/disruptive-technology-czyli-technologie-ktore-zmieniaja-nasze-zycie, 16.05.2025; Regulation (EU) 2024/795 of the European Parliament and of the Council of 29 February 2024 on the establishment of the Strategic Technology Platform for Europe (STEP), https://eur-lex.europa.eu/legal-content/PL/ALL/?uri=CELEX%3A32024R0795, 16.05.2025.

Taking into account the criteria presented in Table 1, each identified technology in the area of transport and logistics in the Silesian Voivodeship was assigned to a relevant technology group by the experts. On this basis, in the last (fourth) stage of the study, two matrixes were prepared to analyse the technologies. Each matrix is a combination of two criteria:

- matrix I - the criterion of efficiency and market age of the technology,
- matrix II - criterion of effectiveness and influence on the technological landscape.

On the basis of the results obtained, the importance and level of development of individual technologies in the area of transport and logistics in the Silesian Voivodeship was indicated, and recommendations were made for their further development.

4. Results and discussion

In accordance with the adopted methodology, the initial phase of the research involved the identification of a range of technologies that facilitate transport and logistics activities in urban and regional contexts. In the second phase of the research, which was conducted in conjunction with experts, four categories were identified, to which the technologies identified during the literature research stage were assigned. The categories encompassed in this study were: passenger transport, freight transport, information flows and warehousing. It is imperative to emphasise that the identified categories are a consequence of the type of flow streams that occur in transport and logistics, and the principal logistical tasks that accompany cities and regions. The extensive range of technologies identified through a comprehensive literature review was then subjected to a more detailed analysis, with the valuable input of experts in the field. The objective of the exercise was to organise, complete and ultimately classify each technology into one of four categories. This process yielded a total of 18 technologies, with five technologies identified for each of the first three areas and three technologies identified for the storage-related area. The list in question is presented in Table 2.

Table 2.
List of identified technologies

Item	Technology area	List of technologies
1	Technologies for freight transport	Technologies for intermodal transport (T1) Technologies for autonomous vehicles and unmanned aerial vehicles (T2) Technologies for low-emission means of transport (T3) Modern technologies for last mile transport (T4) Other technologies for last mile transport (T5)
2	Technologies for passenger transport	Technologies for collective transport (O1) Autonomous vehicles technologies for passenger transport (O2) Technologies for micromobility (O3) Technologies for parking systems (O4) Technologies for integrated transport (O5)
3	Information technology	Intelligent Transport Systems (I1) IoT technologies for logistics and transport (I2) Artificial intelligence, virtual and augmented reality in logistics (I3) Web and mobile technologies for transport and logistics (I4) Other identification and tracking technologies for transport and logistics (I5)
4	Warehouse technologies	Warehouse process automation technologies (M1) Robotics technologies for warehouse processes (M2) Green warehouse technologies (M3)

Source: own work.

The technologies listed in Table 2, in accordance with the adopted methodology, were subjected to expert assessment. As a result, within the first category 'technologies for freight transport', the following were distinguished:

- in terms of efficiency criterion - three key technologies and two experimental technologies;
- in terms of market age - two technologies in the market launch phase and three technologies in the growth phase;
- in terms of impact on the technological landscape - one niche technology, one critical technology and three breakthrough technologies.

Within the second category 'technologies for passenger transport', the following were identified:

- in terms of performance criteria - two core technologies, two key technologies and one experimental technology;
- in terms of market age - one technology in the launch phase, two in the growth phase and two in the maturity phase;
- in terms of impact on the technological landscape, all technologies were considered critical.

Within the third category 'information technology', the following were identified:

- in terms of performance criteria - one core technology, two key technologies and two experimental technologies;
- in terms of market age - two technologies in the launch phase, two in the growth phase and one in the maturity phase;
- in terms of impact on the technological landscape - three technologies were identified as critical and two as disruptive.

Within the fourth category 'technologies for storage', the following were identified:

- in terms of efficiency criteria - two critical technologies and one experimental technology;
- in terms of market age - one technology in the market launch phase and two technologies in the growth phase;
- in terms of impact on the technological landscape - two critical technologies and one breakthrough technology.

Consequently, within the domain of transport and logistics, three core technologies, nine critical technologies and six experimental technologies were identified. With regard to the market's age, it is evident that six technologies are in the introduction phase, nine are in the growth phase, and three are in the maturity phase. In accordance with the initial two criteria of technology assessment in the Silesian Voivodship, namely effectiveness and market age, the technologies in question were examined and subsequently arranged in the form of a matrix, as illustrated in Figure 2.

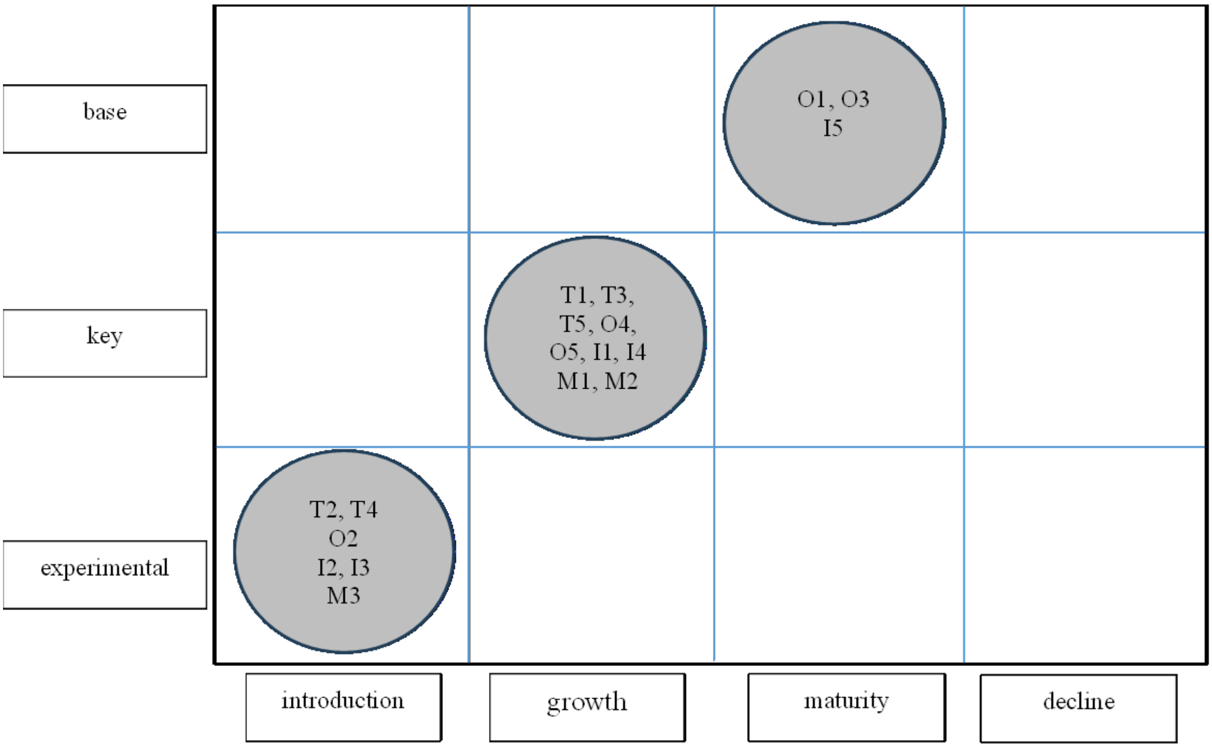

Figure 2. Assessment of transport and logistics technologies in terms of efficiency and market age.
Source: own elaboration.

As demonstrated in Figure 2, within the domain of transport and logistics in the Silesian Voivodeship, three technologies were identified as being in the basic maturity phase. The technologies in question are as follows: technologies for public transport (O1), micromobility technologies (O3) and identification and tracking technologies (I5). These technologies have a strong presence in the market, are extensively utilised, and are characterised by their predictability and standardisation. While the possession of these territories is imperative for the efficient operation of transport and logistics within the province, it does not ensure a competitive edge in this domain. As part of a series of key technologies that are undergoing rapid development, seven technologies have been identified in the area of transport and logistics in the Silesian Voivodeship. The following technologies are to be considered: technologies for intermodal transport (T1), technologies for low-emission means of transport (T3), other technologies for last mile transport (T5), technologies for parking systems (O4), technologies for integrated transport (O5), intelligent transport systems (I1), web and mobile technologies for transport and logistics (I4), technologies for automation of warehouse processes (M1), technologies for robotisation of warehouse processes (M2). The aforementioned technologies are instrumental in ensuring competitiveness in the domain of transport and logistics within the Silesian Voivodeship. It is imperative for the advancement of this domain that these competencies are proficiently attained, as they are distinguished by an average degree of uncertainty and recognised as a pivotal success factor, thus prompting the pursuit of their implementation. These products are readily accepted, and their use contributes to a number of advantages in terms of both cost and quality. Six experimental technologies are currently in the introduction phase. The technologies in question are as follows: technologies for autonomous vehicles and unmanned aerial vehicles (T2), cutting-edge technologies for last-mile transport (T4), technologies for autonomous vehicles in passenger transport (O2), IoT technologies for logistics and transport (I2), artificial intelligence, virtual and augmented reality in logistics (I3), technologies for green warehouses (M3). The technologies previously mentioned are characterised by a relatively high degree of uncertainty and have only limited application in the present day. These solutions represent a state-of-the-art, pioneering approach, and their usability is currently under investigation. It is widely acknowledged that they possess considerable potential and represent a significant opportunity for the future development of the Silesian Voivodeship. Concurrently, it is emphasised that the acceptance of these solutions in practice is uncertain (e.g. extensive use of crowdsourcing).

In accordance with the established research methodology, the subsequent matrix correlates the outcomes of technology assessment in the Silesia Voivodeship, incorporating two distinct criteria: efficiency and the impact of technology on the technological landscape. The results of the study are presented in the matrix in Figure 3.

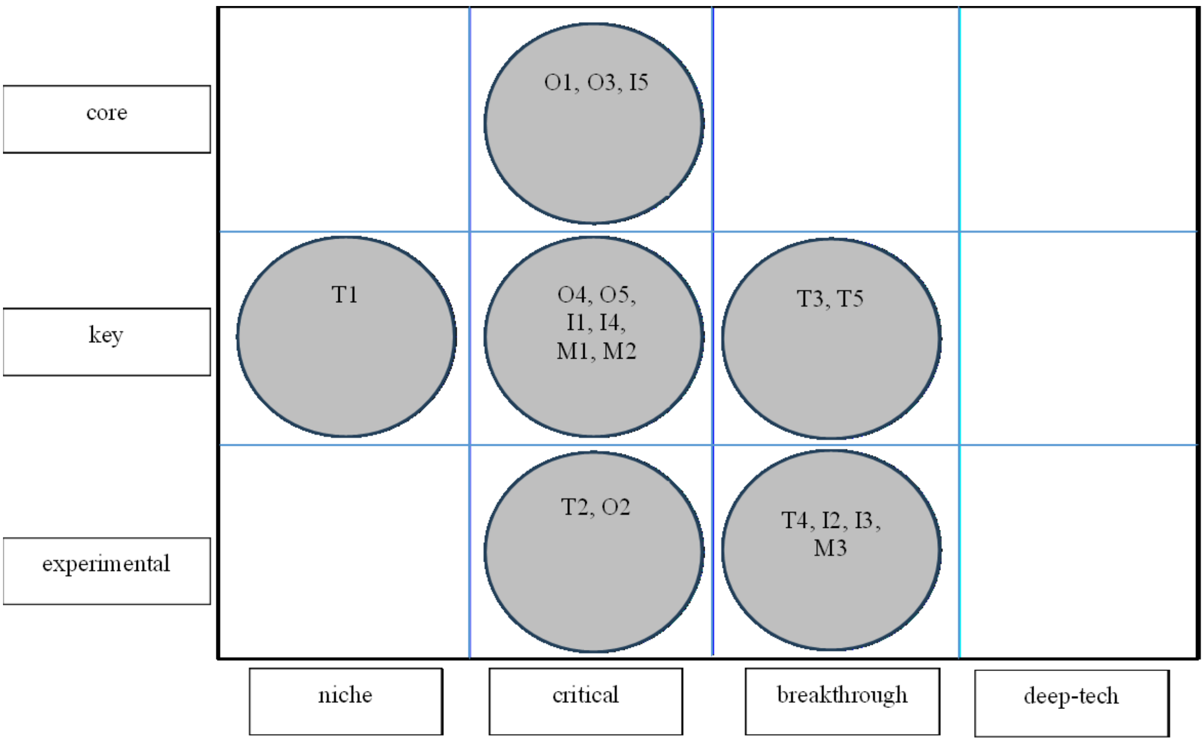

Figure 3. Assessment of technologies in the area of transport and logistics in terms of efficiency and impact on the technological landscape.

Source: own work.

Surveys carried out in the Silesian Voivodship revealed a total of 11 niche technologies, 11 critical technologies and six breakthrough technologies. This finding indicates that the majority of technologies (61%) possess considerable potential for the advancement of the region. Simultaneously, six pioneering technologies have been developed as innovative solutions with the potential to effect substantial changes in the transport and logistics systems of the province, and occasionally even to bring about a complete revolution in these systems. The only identified niche key technology is technologies for intermodal transport (T1). This attests to their pivotal role in enhancing the region's competitiveness in the domain of freight transport. Nevertheless, their utilisation is restricted to a select demographic due to their focus on a particular market segment. Within the critical technologies, three are designated as core technologies, six as key technologies, and two as experimental technologies. It is important to note that all technologies in the domain of passenger transport are classified as critical technologies. Among these, two stand out as being fundamental: technologies for public transport (O1) and technologies for micromobility (O3). The remaining technologies are either key (technologies for parking systems (O4), technologies for integrated transport (O5)) or experimental (technologies for autonomous vehicles in passenger transport (O2)). Furthermore, other technologies for identification and tracking in transport and logistics (I5) were classified as critical core technologies. The critical core technologies encompassed intelligent transport systems (I1), web and mobile technologies for transport and logistics (I4), warehouse process automation technologies (M1), and warehouse process robotisation technologies (M2). Meanwhile, in the domain of critical experimental technologies, in addition to autonomous vehicle technologies for passenger transport (O2), there were autonomous vehicle and unmanned aerial vehicle technologies for freight transport (T2). Among the breakthrough technologies, two key technologies (technologies for low-carbon modes of transport (T3), other technologies for last mile transport (T5)) and four experimental technologies (cutting-edge technologies for last mile transport (T4), IoT technologies for logistics and transport (I2), artificial intelligence, virtual and augmented reality in logistics (I3) and technologies for green warehouses (M3) were identified.

As a result of classifying each of the 18 technologies into the appropriate area in matrix I (summary of effectiveness and age of technologies) and matrix II (summary of effectiveness and impact on the technological landscape), six subsets of technologies in the Silesian Voivodeship were identified. Taking into account their characteristics, recommendations were proposed for them, presented in Figure 4.

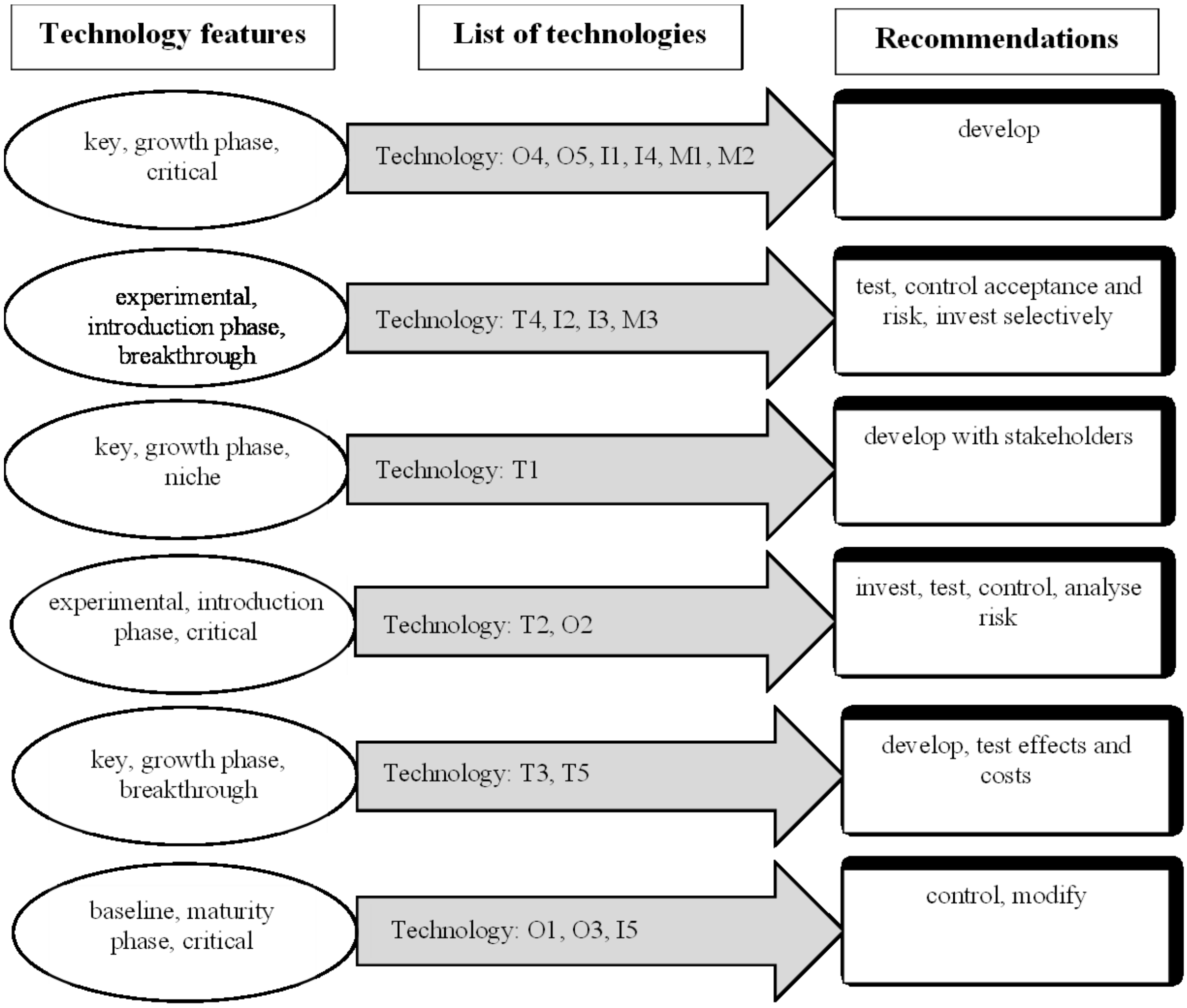

Figure 4. Summary of technologies in the field of transport and logistics for the Silesian Voivodeship – recommendations.

Source: own work.

As outlined in Figure 4, with regard to technologies O1 (technologies for public transport), O3 (technologies for micromobility), and I5 (other identification and tracking technologies), continuous observation and control is necessary. These technologies are fundamental to the operation of passenger transportation within the province. The efficacy of the control measures implemented will dictate the necessity for modifications and upgrades to be made, with the objective of enhancing the technologies in question through the implementation of contemporary organisational and technical solutions.

It is imperative to allocate resources to the development, testing, control, and evaluation of technologies for autonomous vehicles and unmanned aerial vehicles in freight transport (T2) and autonomous vehicles in passenger transport (O2). This approach is essential to assess the potential risks associated with the widespread implementation of these technologies in practical applications. In the case of technologies T4 (modern technologies for last mile transport), I2 (technologies in the area of IoT), I3 (artificial intelligence, virtual and augmented reality), M3 (technologies for green warehouses), some activities are analogous to the previously mentioned technologies T2, O2. The necessity for research is predicated on the assumption that there is a need to control the level of acceptance by different stakeholders. Furthermore, the potential risks of their application must be analysed, and, depending on the results obtained, selection and selective investment will be made.

With regard to T1 technologies (technologies for intermodal transport), due to their pivotal role in the region, their development is recommended. However, due to the niche nature of the project, it is important to strongly involve stakeholders such as, for example, intermodal terminal managers or selected logistics operators in this development. Consequently, cooperation in organisational and financial terms (e.g. public-private partnerships) assumes significant importance. It is evident that development is required in the following technologies: O4 (parking system technologies), O5 (technologies for integrated transport), I1 (intelligent transport systems), I4 (mobile and web technologies), M1 (automation technologies in warehousing) and M2 (robotics technologies in warehousing). It is evident that these technologies are pivotal to the province's functioning. Their extensive implementation has the potential to yield substantial benefits for the region. In relation to the final group of technologies, namely T3 (technologies for low-carbon means of transport) and M5 (technologies for green warehouses), it is recommended that development be pursued. However, it is imperative that the potential effects and financial implications of the proposed solutions be thoroughly examined.

5. Conclusions

Transport and logistics processes within urban and regional systems are supported by a variety of technologies. However, it should be noted that the status and level of development of these technologies may vary across different regions. The paper conducts research into the assessment of technologies in the area of transport and logistics in the Silesian Voivodeship. The study resulted in the identification of 18 groups of technologies, which were subsequently assigned to four categories: technologies for freight transport, technologies for passenger transport, information technologies and warehouse technologies. It is important to note that each of the 18 groups of technologies is quite broad, including a number of detailed solutions that are in practice, at different stages of development. This approach constitutes a limitation of the analyses carried out. Concurrently, it delineates the trajectory of prospective research endeavours, which will centre on the meticulous examination of technologies, encompassing both their intricacies and fragmentation. Another limitation is the lack of separate consideration in the analyses of waste flows in the city, which constitute a significant subsystem of the city's logistics system. This aspect will also be developed by the Authors in further research.

The assessment of technologies was conducted using three distinct criteria, namely technology effectiveness, technology age, and its impact on the technological landscape. The assessment of the Silesian Voivodeship was conducted by experts using research methods. The research enabled the identification of six distinct technological clusters within the domain of transport and logistics in the Silesian Voivodeship. Each of these groups technologies at a similar level of development and use in practice. It is imperative to emphasise that the method of analysis employed is universally applicable, independent of the geographical location in which the research was conducted. However, it is important to note that the assessment itself and its results are applicable to the Silesian Voivodeship. Focusing on a single region does not allow for a comparative analysis. Therefore, this aspect constitutes a limitation of the research. In the subsequent phase of research, it is envisaged that analyses will be conducted for additional regions within Poland and Europe. This will facilitate a comparative analysis of the results obtained.

The presented technology assessment results are targeted at various stakeholder groups. The most important are three groups that participate in the implementation or development of technologies. The primary target group for the results are provincial and city authorities, as the main decision-makers for actions undertaken in the region and cities. Knowledge regarding the status of existing technologies and the identified recommendations is crucial and should be used to: determine directions and plans for regional and city development, develop financial plans, prepare measures to counteract the potential exclusion of various social groups, conduct activities aimed at establishing cooperation with other stakeholders, and conduct information and awareness-raising activities to minimize potential concerns and lack of acceptance among residents. Other stakeholder groups targeted by the results include R&D institutions and TSL companies. These groups should collaborate with cities regarding the transport and logistics processes implemented in their areas. Therefore, knowledge regarding technology assessment and recommendations for their development should form the basis for research and implementation activities. This article does not focus on the stakeholders who will receive the research results or the directions for their use. However, the Authors' research interests and publications address the issue of stakeholders in the city's logistics ecosystem. Therefore, the issue of benefits for various stakeholder groups from the obtained results will also form the basis for the Authors' further research.

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