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STEEL COMPANY IN INDUSTRY 4.0: DIAGNOSIS OF CHANGES IN DIRECTION TO SMART MANUFACTURING BASED ON CASE STUDY

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Purpose: The reason for writing the paper was the strong trend of development of the concept of Industry 4.0. Companies have started their journey to smart manufacturing by applying the key technologies (pillars) of Industry 4.0. A decade has passed since 2011, when the idea of Industry 4.0 emerged as a form of industrial development based on the achievements of the fourth industrial revolution. During this decade, companies have become convinced by the idea of Industry 4.0 and have embarked on projects (investments) that fit into smart manufacturing. The aim of the research was presentation of the key fields of changes in the steel company towards smart manufacturing.
Design/methodology/approach: The author used a case study to achieve the research aim. The subject of the research was one of the largest steel companies, which has a strong position in the global steel market. The presented areas of change of the company fit into the scope of changes belonging to smart manufacturing. In the study, following the company's statement, it was assumed that the implemented investments will create "smarter manufacturing" no "smart manufacturing" because their number and scope does not entitle either the company itself or the author of this paper to state that the changes made already at this stage create smart manufacturing in the steel company.
Findings: The result of the case study is a model – a general concept – for the introduction of smart manufacturing in an enterprise. The term model was used for popular scientific purposes, as a form of generalisation of the presented scope of changes in the studied enterprise.
Research limitations: The author is aware that the company used for the research may not constitute a sufficient area of research to formulate generalisation constructs on its basis, but she points out that the article is a part of a broader research, and the presented fragment of the research was used for the purpose of popularising knowledge on changes taking place in Industry 4.0.
Practical implications: The paper promotes smart manufacturing projects in the steel sector. The practical implication of the paper is a proposal for a pathway to build smart manufacturing, which has constructs that are versatile enough to be used to create company pathways in other industry sectors of the economy.

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Originality/value: The article is part of the very topical theme of Industry 4.0, which has already been popularised to such an extent that it has become a reality and not just a proposal (future) for industrial development under the conditions of the Fourth Industrial Revolution. The paper describes actual projects for building smart manufacturing in the steel company.

Keywords: steel company, smart manufacturing, smarter steel.

Category of the paper: case study.

1. Introduction

Industry 4.0, as a new direction for many of the world's economies in the fourth industrial revolution, has accelerated the development of companies. Today, there are already enterprises that have introduced advanced technologies that create smart manufacturing. The accession of companies to the creation of Industry 4.0 is carried out according to the requirements of the new development concept, which are: personalisation of products, cyber-physical production systems, artificial intelligence, augmented and virtual reality, Big Data, IoT, ubiquitous integration (Kagermann et al., 2013). For the success of companies that adopt the co-creation of Industry 4.0 as their development direction, it is necessary to invest in technologies that combine physical objects with virtual solutions. The rapid development of advanced technologies is conditioning changes in manufacturing systems that are agile enough to deliver products tailored to their individual customers' needs (Arora et al., 2008). Companies in Industry 4.0 are making changes to be smart. There is no single solution that can be considered to lead the changes that build smart manufacturing. The form of the complexity of change can be seen, for example, in the RAMI 4.0 model with many processes and technologies (Resman et al., 2019). Innovations and investments in enterprises are made both in core processes, which include production, and in supporting processes, with a particular focus on logistical processes outside the enterprise. The development of enterprises in Industry 4.0 is a set of many technological, organisational and human resource changes, all of which make up the smart environment within and around companies (Rüßmann et al., 2015; Santos et al., 2017, Davis, 2012).

The nature of each company is its development in Industry 4.0. The development is based on business improvement under the conditions of the Fourth Industrial Revolution. Each company is made up of an organisational structure, human resources and technology that provide opportunities for growth. The key directions of change that a company adopts are enshrined in its development strategy. By adopting Chandler's rule, the company will follow the strategy, not the other way around. At the stage of building smart manufacturing, it is important to determine the key areas of change and the key processes in which the changes will be implemented in companies on their development paths in Industry 4.0 (Gajdzik, 2022a, 2022b, 2022c).

The main problem for companies starting to implement a development strategy based on the pillars of Industry 4.0 is to find areas with the potential to create a smart manufacturing. Przedsiębiorstwa nie mogą przeinwestować lub nie doinwestować strategicznych obszarów biznesu. Companies cannot over-invest or under-invest in strategic business areas. New fully automatic technologies and artificial intelligence are very expensive. The choice of areas for change in companies towards Industry 4.0 is an individual decision by top management. Not all companies will reach Industry 4.0 as part of their development, some companies will not build a smart environment. It is easier to make changes for very large and large enterprises belonging to strong capital groups, very often with many years of experience in business. The variation in the degree of investment in high technology also applies to industrial sectors. In many economies around the world there are sectors (industries) where smart solutions are easier to introduce, if only because of the type of production and type of customers. Such sectors include the automotive, footwear, computer (electronics) and food sectors. In contrast, it is more difficult to introduce changes towards Industry 4.0 in the mining, fuel, chemical and metallurgical industries. Despite some difficulties in building Industry 4.0 in all industries, each industry is attempting to set its own development path in reaching the goal of being a participant in the cyber-physical systems (Gajdzik et al., 2021a; Deloitte, 2018).

On the basis of the above introduction about the company development in Industry 4.0, the following research objective was adopted: to establish a path of action in the process of transformation of steel industry enterprises in Industry 4.0 by building smart manufacturing. This study is part of a larger research project on the transformation of the steel producers sector in Poland together with business-related enterprises under the conditions of the ongoing fourth industrial revolution. The presented research part is based on a case study of a global steel producer, where the process of development towards Industry 4.0 is most visible.

The structure of the paper consists of a literature part and a research part. The literature part aims to present the essence of knowledge about Industry 4.0. The concept of Industry 4.0 has been strongly popularised by political, business and scientific circles since 2011. Many scientific studies and research reports have already been written on Industry 4.0In the Web of Science scientific database, more than 17,000 publications searched for the keyword 'Industry 4.0' were registered between 2011 and 2021. The research part is the result of an analysis of investment projects implemented in a steel company. The analysis was carried out on the basis of publicly available information, using reports published by the surveyed company on investments carried out as part of the company's development strategy (resulting from the development strategy) for the coming years. The work concludes with a summary of the stages of steel design (construction). This summary of implemented changes became the basis for determining the entity's path in Industry 4.0 based on smart manufacturing. The usefulness of the research results presented in the paper for building knowledge about the transformation of steel enterprises in the conditions of Industry 4.0 is due to the purposeful selection of the entity for the case study, which was the largest steel producer (until 2019, it occupied the first position in the world ranking of steel producers conducted by the World Steel Association).

2. Industry 4.0 – the key information about the industrial development

A consequence of the fourth industrial revolution is Industry 4.0, which is being introduced in many economies around the world. The term Industry 4.0 (Industrie 4.0 – a nomenclature from German)- abbreviated to I 4.0 was coined by German business and government circles. The term 'Industrie 4.0' appeared at the Hanover Electronics Fair in 2011. Since 2012, the name 'Industry 4.0' has become very popular. The pillars of Industry 4.0 are: autonomous robots, Internet of Things, cloud computing, huge data sets (Big Data), augmented and virtual reality, interoperable technologies, IT-computer process support systems, additive (incremental) manufacturing, machine-to-machine (M2M) communication technologies, artificial intelligence and autonomous robots, data transfer security support technologies (Kagremann et al., 2013). Industry 4.0 is developing towards the flexible and intelligent manufacturing of products - Smart Manufacturing, (SM). The word 'smart' is used to emphasise (expose) the interaction of the real and virtual worlds, with a particular focus on artificial intelligence (AI), which is being introduced in manufacturing companies to optimise processes and provide 'agility' to the enterprise through device access to IoT (Dais, 2014; Davis, 2012). New advanced (high) manufacturing technologies offer the opportunity to increase production efficiency and minimise production 'delays' resulting from the unreliability (weakness) of the human factor and traditional machinery (Schwab, 2016). Autonomous robots and collaborative technologies are opening up new possibilities for manufacturing products. High technologies have the ability to monitor and transmit data from devices to decision-making centres on an ongoing basis and control devices autonomously through AI algorithms, which affects the speed and flexibility of production (Wiesmüller, 2014; Wang et al., 2016).

In Industry 4.0, a significant part of production is carried out by means of intelligent and digital technologies that control processes in companies. Computerised manufacturing systems are equipped with network links with digital twins that communicate with other facilities and systems, transmitting information about the operation of equipment (machines) in real time and improving their technical performance via internet links. The interconnection of the structures of all manufacturing systems leads to the emergence of cyber-physical production systems (CPPS), in which high technology communicates via networks. Manufacturing is highly autonomous. Intelligent technologies work without humans or with very limited human input. The structures of cyber-physical systems are extensive. The cyber-physical system is made up of intelligent machines, autonomous robots, storage systems, ICT, autonomous technologies, intelligent objects, etc. The Industrial Internet of Things (IIoT) facilitates the transfer of information from device sensors (machines) to a decision-making centre, as well as improving machine-to-machine (M2M) and machine-to-product (M2P) communication. Cyber-physical systems operate in real time, sending data to a local server or cloud server, where data analysis takes place and predictive models used for process optimisation and machine learning are built (Hermann et al., 2015; Branca et al., 2020).

Industry 4.0 technologies are so popular that companies have embraced them because the smart environment creates additional business benefits. Companies with smart technologies report productivity gains and lower manufacturing costs, higher product quality (manufacturing accuracy) and higher customer satisfaction with personalised products. In resource consumption, companies report decreases in raw material and energy consumption. In addition, new technologies emit less pollution and waste and improve occupational safety (BCG report, 2018). Market and scientific researchers confirm that the larger the company, the greater the visible impact of new technologies on the listed set of benefits (Czupryna-Nowak, 2020; Göll and Gracel, 2017). The quoted statement was the main argument (for the author of the publication) for choosing the largest steel producer for the case study in the empirical part of the work.

At the stage of change so far, companies have not developed a universal path for the implementation of the technologies that make up Industry 4.0. Decisions by companies to implement next-generation technologies are the result of analyses of the methods and techniques used to date to handle processes, as well as existing IT solutions and the possibility of their expansion in existing business structures (Kuhn, 2015). It is only possible to identify a few common stages, the beginning of which is the adoption of a development strategy based on smart technologies and the establishment of units (departments) for the digitisation of business and high technology manufacturing. Subsequent stages depend on decisions on pilot investments planned for the coming years in the company. The investment projects implemented, based on the pillars of Industry 4.0, will create smart manufacturing. The implementation of solutions starts with a few selected scopes of technological innovation up to the next. The number of projects is increasing, resulting in smart environments within cyber-physical manufacturing systems to smart factories (Gajdzik et al., 2021, Soldaty, 2018). When building a smart environment, companies use the specialist services of the IT industry. The IT industry designs full or fragmented digital business models according to the requirements of different industry sectors. The IT solutions available on the market are not universal, even though certain modules are repetitive, and therefore need to be tailored to the company's specific operations, organisational structure and business process scopes.

The lack of a universal pathway in Industry 4.0, in the form of a methodology for enterprises that have embarked on building a smart environment, was the inspiration for the preparation of the empirical part of this article. The choice of the steel sector as the industry used to perform the analysis is dictated by the author's scientific area, which she has been dealing with for years by researching and describing changes in the steel industry in Poland. The capital group used in the case study operates a company in Poland, which is, in this country, the largest steel producer. The case study analysis therefore has a double utility. The first arises from the fact that the capital group is a benchmark in the global steel market and the second arises from the fact that it operates in Poland through one of its companies, which is, in turn, a benchmark in the Polish steel industry.

3. Direction on smart manufacturing in steel company – the case study

Methodology

A case study is a detailed description of a phenomenon or process, carried out to identify causes and conditions and interactions with other phenomena, as well as the effects of change. The analysis of a multiple case study helps to clarify the mechanisms of the activities under study and assess their effects (Czakon, 2011). The case study outlines a picture of the phenomenon or process under investigation in the context of existing enterprise capabilities and business conditions. The information for the case study comes from the enterprise under study (Apanowicz, 2020). A case study consists of the following stages: (i) determination of the research topic and research objective (ii) presentation of the analysed enterprise this stage also called enterprise characteristics opens the case study; (iii) discussion of the researched topic and its description by information about changes in the analysed enterprise, (iv) evaluation of the extent of changes and formulation of final conclusions or models in relation to the research objective. The results of the case study are model processes or best solutions or a methodology of operation On the basis of the case study, conclusions relevant to other companies can be drawn (Apanowicz, 2020).

Referring to the presented methodological steps for the execution of the case study, a research topic was established (in line with the first step), which is changes towards smart manufacturing in a steel company. The aim is to outline a path for the introduction of smart steel production. The scope of the research concerned technological and organisational changes implemented in a strong steel group in the global steel market. The manufacturer produces around 10% of the world's steel production annually. The information presented in the article was from studies (reports) available on the web pages of the steel company under study.

Object of the case study

The analysed capital group has been one of the world's leading steel producers for years. The mills in the analysed capital group produce approximately 10% of the world's steel production annually. The group operates in 60 countries on three continents. In terms of steel production, the capital group is a leader not only in the world steel market, but also in the European market. The Capital Group acquired steel mills that were being restructured in Central and Eastern European countries, including Poland. The restructuring process of the steel industry in Poland was carried out with the participation of foreign capital (Gajdzik, 2012). Foreign capital, including the analysed group, strengthened its position in the global steel market through strategic mergers (Gajdzik, and Sroka, 2012). The group in question is the result of a merger between two large capital groups. The group owns both the steel mills and the companies that make up the supply chain (coking plants, mines, logistics centres). The groups has a research and development (R&D) centre and analytical laboratories.

Smarter manufacturing – key projects based on case study

The analysed group adopted an action strategy, which is described by the slogans: smarter future, smarter manufacturing and smarter steel. Citing these slogans, the author wondered: Why does the company under study use the statement 'smarter' and not 'smart'? The answer was formulated based on the results of the research – a case study. The group's action strategy with the adopted statements: "smarter future", "smarter manufacturing" and "smarter steel" is the first stage of changes on the company's way to participate in the development of Industry 4.0. The provisions introduced in the strategy set new directions of development, which in the future will create smart manufacturing in the whole group of companies belonging to this owner.

The steel company invests in smart steel manufacturing based on three business pillars, which are:

- protection of the natural environment through the use of new steelmaking technologies, including among the priorities: reducing emissions of atmospheric pollutants, especially CO2; limiting the use of electricity generated from coal in steelmaking processes,
- improving steelmaking processes through the implementation of artificial intelligence (AI) and advanced automation in all processes of the business,
- personalising steel products for key customers, which in the case studuy are the automotive and construction sectors, using the latest generation of technologies and co-creating technologies with participants in the value chain.

These key areas of change, together with the provisions for smarter manufacturing in the development strategy, are implemented through technological investments, organisational and process changes, accompanied by changes from the area of human factor reorganisation.

The case study presentation summarises four areas of change:

Field 1: Key technological changes.

Field 2: Process improvement.

Field 3: Organisational level of change.

Field 4: Human factor reorganisation.

The selected fields of change are implemented simultaneously at the same time. Changes are implemented at multiple levels of the organisation. The selected areas (stages) of change organise the scope of the changes implemented in the capital group under case study.

Field 1: Key technological changes. The company has developed a holistic vision of digitalisation that includes the Internet of Things (IoT), Big Data and Artificial Intelligence (AI). The synergy of these three areas requires a lot of technology and process investment. Key areas of change include digitalisation, manufacturing robotics, data analytics and Big Data, nanotechnologies, 3D metallurgy and the circular economy. Business digitalisation projects are steered by the Centre of Digital supported by data collection technologies and ICT thematic platforms. Technological improvements through automation of operations are being made in production, delivery and warehousing. Autonomous cranes and overhead cranes with election identification functions, drones, sensors on process plants, sensors for measuring the efficiency of technology, autonomous vehicles, among others, have been used to automate work. The scope of operations of each technology has been established and presented in the investment projects. Example of drone tasks: (i) assessing the maintenance needs of in-service facilities, technologies and transport networks in companies, (ii) minimising risks to employees who would have to work on high structures to determine the condition of a facility, (iii) tracking energy consumption – drones with infrared cameras moving at a fixed height measure the energy intensity of facilities and technologies. Example of AI tasks: (i) product image recognition, (ii) model creation – digital twinning – a set of models used to optimise physical assets and production processes using data collected from equipment sensors (installations), (iii) machine learning. Example of digital twinning: sensors create a digital imprint of a product to be delivered to the next process. AI is used for product quality control and process control. An example of the application of AI in a steel rolling process: the production decision to release a weld in a hot rolling mill is made on the basis of image recognition of the width of the cold coil. The operator has applied the latest in product parameter control to improve product quality. In scaling the technical parameters, control algorithms were applied according to the requirements of customers in the automotive and construction industries - these industries are the consumers of steel products manufactured in the entity under study. In improving the performance of steel products, the steel mills produce lightweight products for the cars of the future, unique products for structures and skyscrapers, railway rails for high-speed transport, steel sheets for equipment and facilities operating in extreme weather conditions and introduces many other innovations in steel products. Technological innovations, including the use of high technologies, are supported by dedicated IT and computer applications in the form of a catalogue of steel solutions to serve the automotive and construction markets by launching thematic programmes in the area of cooperation during the design, manufacture and delivery of products.

The company is constantly implementing maintenance improvements. New technology – 3D printers are used to produce spare parts for machines. In accordance with the TPM concept, companies in the group optimise the operation of technologies – parameterisation of technology operation, measurement of machine (technology) performance, prevention of machine failures. 3D printers with the highest product accuracy parameters are used to manufacture steel products for customer markets (3D metallurgy).

Building the holistic model of steel production requires the installation of thousands of intelligent sensors and sensors to transmit data from the machines to the decision-making centre. Basic technological installations, e.g. the blast furnace together with continuous steel casting equipment, are controlled using advanced information and computer systems. The company is constantly improving its IT and computer systems and communication servers. The manufacturer processes large sets of data (Big Data) across the entire network of capital links in the supply chain, from the sourcing of raw materials to the production of steel to the distribution of final products. The capital group has a central system for decision-making and process monitoring across all plants. One element of process control is product life cycle analysis and circular economy.

Field 2: Process improvement. The processes are improved according to the principle of 'process-based product development'. Investment in the area of: process improvement is the responsibility of the process research team, which works closely with individual units across the company. The aim of the projects is to improve technology reliability and process efficiency. In process improvement, the company uses the ACO algorithm (Ant Colony Optimization). The algorithms involve finding paths to reach a destination in realizing processes. At the beginning of the path is the individual customer order (suction system). Process tracking is implemented through computer vision (CV) systems, which provide a picture of the entire production environment. The algorithms determine selected paths for process optimisation. At the end of the path are the products that customers have ordered. The first fully commissioned AI-based project was the recognition of wagon numbers at raw material plants. Further projects are in the pipeline with algorithms to recognise the type of material moved by cranes or to recognise the level at which liquid metal fills a tub. In improving processes – by optimising activities and parameters - the manufacturer has applied the following principles: (i) full standardisation and modularisation of processes (ii) flexible modular combination of technologies and processes (iii) networking of processes within the group and in supply chains (iv) computer optimisation and virtualisation of process flows and simulation of planned changes (v) continuous development of processes in a whole product life cycle (LC) arrangement, (vi) cooperation of humans and robots (vii) identity of components and machines in communication in cyberspace (viii) integration of everything (machines, ICT, processes). The companies in the study group have mobile inspection teams (inspections) which, using information and computer systems, check the work of the equipment. Inspections are carried out by professional maintenance (PM) services and autonomous maintenance (AM) operators. The services have a computer application installed on their phones, each employee scans a QR code placed on the facility and confirms that the task has been completed after the inspection. Data from the mobile devices of the operators of each machine and process plant is sent directly to the ERP system.

Integrated IT and computer systems for tracking the production of steel products have been installed at steel mills. The solution makes it possible to view the current status of production, increase the throughput of the production line, speed up the quality acceptance of products and reduce the risk of human error. In addition, the manufacturer used a system of communication of operators with machines and technological installations in the cyber-physical space – employyees (equipment operators), instead of computer keyboards and control panels, use smart helmets and glasses, which are a new form of communication with machines.

A steel product defect detection system has been introduced to steel mills with smart technologies, including: (i) the roll defect detection system supports the hot mill grinder – the latest generation of measurement systems used in the system contributes to the effective detection of surface cracks and defects hidden deep beneath the surface, including cracks under other metal, (ii) a radar measurement system to determine the filling level of the coke chamber after backfilling with coal mixture and levelling, based on the data obtained, the chamber backfilling operations can be better carried out while reducing emissions to the environment.

Field 3: Organisational level of change. The company has business digitalisation units at senior management level. The company has a global R&D centre. Process improvement is handled by process research teams. Technology development, on the other hand, is the research area of the digital excellence centres. The group has its own research laboratories. At top management level, there are directors of business digitalisation and directors of advanced technology and AI. Top management works with the business digitalisation staff and the Global R&D Centre with research laboratories. Supporting the digitisation teams are the Research and Development (R&D) Departments and the segment managers for information and data at IT department (division) level, located in the company's divisions and manufacturing processes.

At group management (directorate) level, there is an office: Global R&D, which is the main driver of change for the entire corporation. The entity has its own research laboratories, which collaborate with the engineering divisions to accelerate plant automation projects and the implementation of advanced AI technologies. The entity also has digital laboratories that act as training and innovation centres for employees, students and local startups.

Field 4: Human factor reorganisation. The capital group is focused on human resources development. For more than a decade, the group has used the 70/20/10 model to build staff competence (Gajdzik, 2016). In European countries, the group struggles with the generation gap and controls staff turnover (Gajdzik, and Szymszal, 2016). The company needs young engineers with digital skills. The number of employees with digital skills is increasing year on year, with IT specialists making up between 10% and 20% of the workforce. The IC systems department, as part of its Design Thinking activities, supports the company during the building of the cyber-physical modules of the manufacturing system, including the definition of processes and provides tools to create a risk analysis during system implementation. In addition, the IT Departments support the development of a timetable for the next stages of implementation and the methodology for working on advanced technologies in group companies. The latest virtual simulation technologies are used in the training of staff, particularly in the area of safety and improving working methods. The manufacturer, for many years now, has been betting on the development of soft skills, the share of which in the total number of training courses is constantly increasing (Gajdzik, Wolniak, 2022a, 2022b).

The list of changes cited, in the four areas cited, is open-ended, and the changes implemented do not exhaust the broad scope of building smart steel production in mills (Gajdzik, 2022b, 2022c). The companies belonging to the capital group in question differ in their degree of maturity to operate under the conditions of I 4.0. In the Polish market, this level can be defined as 3.5, on a scale from 1 to 5, where 1 is the lowest assessment of the advancement of changes towards the creation of smart steel production (Gajdzik, 2022a).

The way of steel company to smart manufacturing – the first steps

On the basis of the presented case study, the company's path towards achieving the requirements of Industry 4.0 and building smart manufacturing was determined. Changes are introduced at all levels of the organisation and are initiated by the provisions of the enterprise development strategy. The enterprise development strategy is the main document (plan), for all enterprises in the group, for building smart manufacturing. Regardless of the location of the enterprises, the adopted directions of development, are the signposts of change in Industry 4.0. In the analysed enterprise, the directions concern three technological areas, which make up the holistic business model (Figure 1).

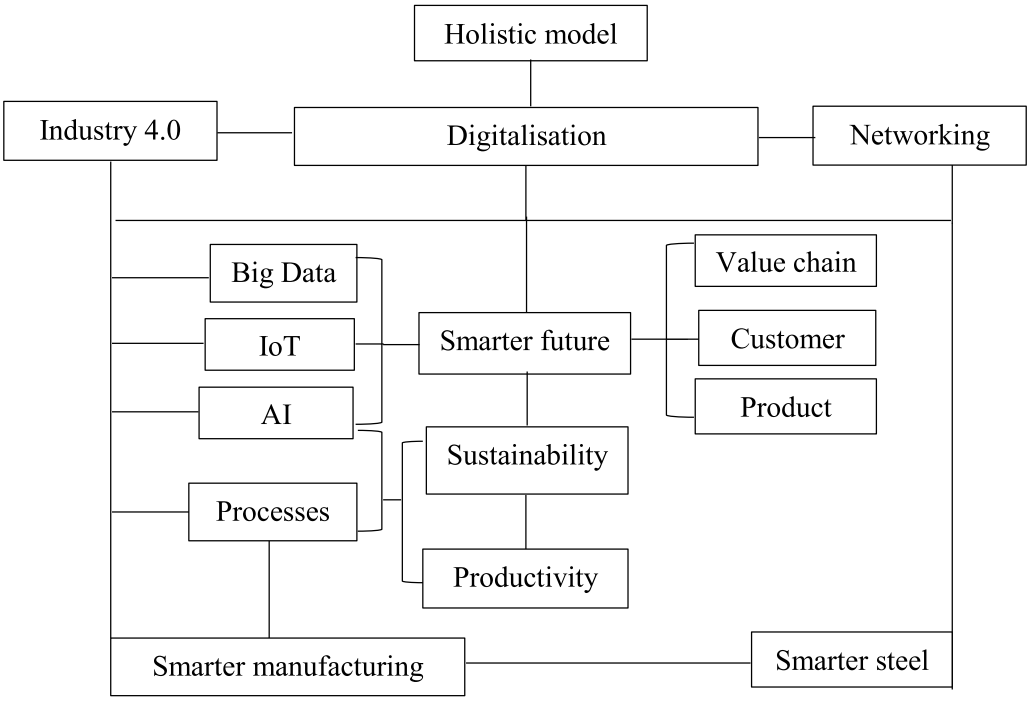

Figure 1. Holistic vision of business in Industry 4.0. Own elaboration.

Three Industry 4.0 technologies are leading the way in building the smart manufacturing: Big Data, IoT, and AI. Improving manufacturing and other processes requires: the use of standardisation and modularity, integration of IT and computer systems, introduction of procedures and systems for personalising products, investment in concurrent technologies, expansion of autonomous IT and computer systems for process control and decision-making, 3D printing of spare parts to ensure continuity of production and achieve higher efficiency of machines under TPM, full automation of activities and an increasing number of activities performed by robots. Technological changes are accompanied by organisational changes. The plants of the studied ownership group are creating additional Top Management positions in the rank of directors for business digitisation and smart manufacturing, who are responsible for the company's strategic projects in Industry 4.0. New positions are also being created at lower levels of the organisation, assuming that the company has a process structure that facilitates the company in building a smart environment. A strong support for companies implementing smart manufacturing projects are internal R&D departments and research laboratories.

Parallel to the technological and organisational changes, a reorganisation of the human factor in the study group is taking place. In Industry 4.0 there is an increasing demand for staff with digital skills. Companies are following two parallel paths: (i) development of the company's staff (training, recruitment, redeployment) (ii) purchase of IT services from external digital service providers. The development of basic digital skills among employees is important. Employees in production positions are required to operate ICT equipment and have IT knowledge. In addition to employees with basic digital skills, the company has a demand for employees with advanced digital skills, which it recruits externally. The existing arrangement of durable (technical) and soft (social) skills is strongly reinforced by digital skills (Grebski, Gajdzik, 2022).

The presented model of building smart manufacturing in the analysed metallurgical company (Fig. 2) is a generalised form of planned and implemented investment projects of the studied enterprise. The presented model can be used to determine the path of conduct of enterprises of other industries at the stage of determining the smart enterprise strategy. However, the author emphasises that the analysed group (steel company) calls the degree of preparation for functioning in Industry 4.0 as 'smarter' and not 'smart'. It can be expected that in the future the scope of change will intensify and the company will introduce the notation 'smart manufacturing' in its development strategy.

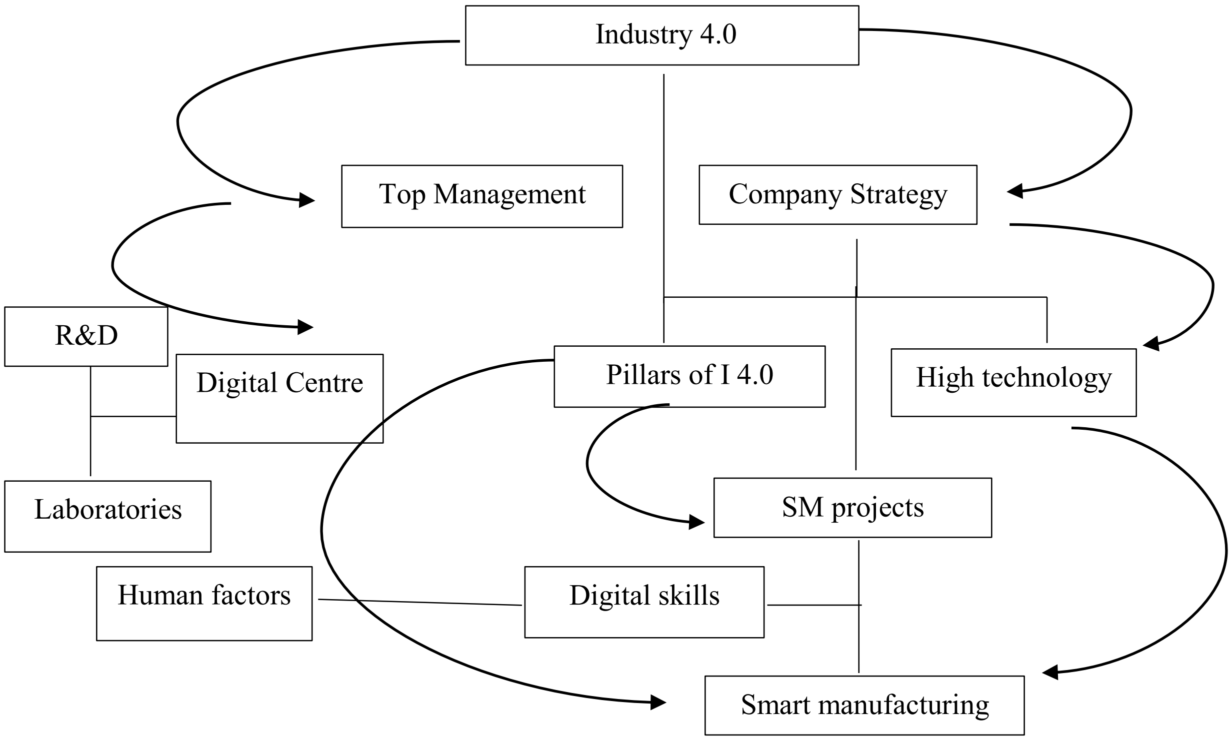

Figure 2. The development way of the company in Industry 4.0 – the key phases and fields of the transformation model. Own elaboration.

Conclusion

The paper is based on the case study, which was the steel company in the global market. The analysed company is a recognised benchmark in the global steel market. The extent of the changes implemented by the company based on the requirements of Industry 4.0 is the beginning of its long road to the smart steel manufacturing. The number of projects will increase and the improved internal processes will be strongly linked to those of key customers in the market. It is noteworthy that in the holistic vision of the digitalisation of the enterprise, the three technologies of Industry 4.0, which are Big Data, IoT and AI, are placed at the centre of change. These technologies are new and strongly popularised in the concept of Industry 4.0. The triad of technological symbiosis (Big Data, IoT and AI) is the core achievement of the Fourth Industrial Revolution. In addition to these technologies, the company continues to make technological investments based on the achievements of the third industrial revolution. Such investments include a package of projects in the area of business digitalisation. The digitalisation of industry started several years ago (1990s) and is still ongoing. In the new business model, plants of the analysed group link business digitalisation with the integration of business processes and with internal and supply chain technologies. Such the setup, further supported by the presented triad of technologies: Big Data, IoT and AI, provides the foundation for building the smart steel manufacturing.

The three pillars of change towards smart manufacturing identified in the case study are among the key pillars of Industry 4.0 reported in the literature. Although, here too, there are differences in the number of pillars (Industry 4.0 technologies) identified by authors or organisations. G. Erboz (2017) describes four pillars of Industry 4.0: CPS, IoT, cloud computing and cognitive computing. S. Greengard (2015) focuses on cyber-physical systems (connections between the real and virtual worlds), the Internet of Things (IoT) which increases the data available as different products can be connected to the Internet, the Internet of Services (IoS) and the smart factory. C. Senn (2019) and B. Sniderman (2016) characterise nine technologies of Industry 4.0. Eleven components of Industry 4.0 are studied by the Boston Consulting Group (Rüßmann et. al., 2017). The broadest typification of Industry 4.0 technologies includes: Big Data, augmented reality, 3D printing, cloud computing, autonomous robots, cyber-security technologies, computer simulation technologies, system software, process visualisation technologies, integrated technologies and building environments for vertical and horizontal integration, IIoT. The set of technologies that make up Industry 4.0 is an open and constantly expanding set. Smart manufacturing (SM) projects based on collaborative technologies of Industry 4.0 and real-time management of processes in enterprises and in the whole supply chain. SM integrates the latest information and communication technologies (ICT) into manufacturing systems to enable real-time response to changing demands and conditions in the factory, in the supply network, and in customer needs. In this new paradigm, the Internet of Things (IoT), the digital factory, and cloud computing technology play major roles in transforming the rigid hierarchical architecture into a flexible style (Kulvatunyou, 2016). Smart manufacturing projects in specific enterprises vary in scope of change, size, type. Each enterprise develops and implements projects according to its capabilities and development goals. The technological solutions of Industry 4.0 are a key component of the new business models that are created in Industry 4.0 on the basis of the implemented changes in enterprises. In addition to key technologies, the architecture of the model is formed by human resources, organisational structure, decision-making powers and management systems (Grabowska, 2022). The foundation of the model is business processes, which, supported by new technologies, are continuously optimised. Data from equipment is collected in real time, performance metrics are collected and used to control processes, which are visualised and optimised in real time. Quality, efficiency and optimisation are embedded in smart technology algorithms and process control systems (Gajdzik, 2022a). Business models created in Industry 4.0 are strongly customer-oriented through product personalisation. Personalisation is a key paradigm of Industry 4.0 (Grabowska, 2022; Grabowska, and Sanik, 2022). Each enterprise needs to be tailored to the customers' area of activity. Large enterprises are divided into divisions that create value for customer segments of different industries. In the digital transformation taking place, more and more companies are also attaching importance to shortening supply chains (Hwang, and Rau, 2006). Industry 4.0 technologies, on the one hand, represent an opportunity to modernise business and, on the other hand, a challenge for companies to invest in reducing their Carbon Trust and carbon-based energy intensity. Industry 4.0 companies cannot ignore the assumptions of the New Green Deal. Today's companies, even more than a few years ago, are striving to strike a balance between technology development and improving the quality of life and the quality of the environment. The new technologies of Industry 4.0 are an opportunity for companies to develop their business in line with the development of societies and economies. (Gajdzik et al., 2021b).

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References

1. Apanowicz, J. (2002). *Metodologia ogólna*. Gdynia: Wydawnictwo Diecezji Pelplińskiej „Bernardium".
2. Arora, N., Dreze, X., Ghose, A., Hess, J.D., Iyengar, R., Bing, J., Joshi, Y., Kumar, V., Lurie, N., Neslin, S., Sajeesh, S., Su, M., Niladri, S., Thomas, J., Zhang, Z.J. (2008). Putting one-to-one marketing to work: Personalization, customization, and choice. *Science & Business Media.* Springer, p. 310.
3. BCG: The Boston Consulting Group (2018). *Przemysł 4.0 PL. Szansa czy zagrożenie dla rozwoju innowacyjnej gospodarki?* Retrieved from http://image-src.bcg.com/Images/BCG-Przemysl-4-PL_tcm78-123996.pdf, 2018.04.20.
4. Branca, T.A., Fornai, B., Murri, M., Streppa, E., Schröder, A.J. (2020). The Challenge of Digitalization in the Steel Sector. *Metals*, *10*(*2*), 288. https://doi.org/10.3390/met10020288.
5. Czakon, W. (2011). Metodyka systematycznego przeglądu literatury. *Przegląd Organizacji*, *3*, 57-62.
6. Czupryna-Nowak, A. (2020). Grupa przedsiębiorstw wdrażających koncepcję Przemysłu 4.0 sektora MŚP w Polsce. In: A. Michna, J. Kaźmierczak (Eds), *Przemysł 4.0 w organizacjach*. *Wyzwania i szanse dla mikro, małych i średnich przedsiębiorstw* (pp. 29-45). Warszawa: CeDeWu.
7. Dais, S. (2014). Industrie 4.0 – Anstoß, Vision, Vorgehen. In: T. Bauernhansl, M. ten Hompel, B. Vogel-Heuser (Eds.), *Industrie 4.0 in Produktion, Automatisierung und Logistik*. Anwendung, Technologien und Migration, 625-634.
8. Davis, J., Edgar, T., Porter, J., Bernaden, J., Sarli, M. (2012). *Smart manufacturing, manufacturing intelligence and demand-dynamic performance*. FOCAPO, 47.
9. Deloitte Insights (2018). *The Industry 4.0 paradox. Overcoming disconnects on the path to digital transformation*. Deloitte Development LLC. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/cn/Documents/energy-resources/deloitte-cn-er-industry-4.0-paradox-overcoming-disconnects-en-full-report-190225.pdf, 2020.09.09.
10. Erboz, G. (2017). *How To Define Industry 4.0: Main Pillars of Industry 4.0.* 7th International Conference on Management (ICoM 2017). Nitra, Slovakia, November 2017. Retrieved from https://www.researchgate.net/publication/326557388_How_To_Define_Industry_40_Main_Pillars_Of_Industry_40, 2019.06.09.
11. Gajdzik, B. (2022b). How Steel Mills Transform into Smart Mills: Digital Changes and Development Determinants in the Polish Steel Industry. *European Research Studies, 25(1),* 27-42. doi: 10.35808/ersj/2827.

12. Gajdzik, B, Grabowska, S., Saniuk, S. (2021b). Key socio-economic megatrends and trends in the context of the industry 4.0 framework. *Forum Sci. Oecon.,* 9(3) 5-21. DOI: 10.23762/fso_VoL9_no3_1 http://ojs.wsb.edu.pl/index.php/fso/article/view/407/276.
13. Gajdzik, B. (2012). *Przedsiębiorstwo hutnicze po restrukturyzacji*. *Dynamika zmian w krajowym sektorze hutniczym w latach 1992-2010.* Gliwice*:* Wydawnictwo Politechniki Śląskiej.
14. Gajdzik, B. (2016). Zastosowanie metody 70-20-10 w przedsiębiorstwie produkcyjnym. *Zarządzanie Przedsiębiorstwem*, *19(1),* 8-12.
15. Gajdzik, B. (2022a). Frameworks of the Maturity Model for Industry 4.0 with Assessment of Maturity Levels on the Example of the Segment of Steel Enterprises in Poland. *J. Open Innov. Technol. Mark. Complex*., *8*, *77*. doi.org/10.3390/joitmc8020077.
16. Gajdzik, B. (2022c). Key directions in changes from steelworks 3.0 to steelworks 4.0 with analysis of selected technologies of digitalizing the steel industry in Poland. *Management Systems in Production Engineering*, *30(1),* 46-53.doi 10.2478/mspe-2022-0006.
17. Gajdzik, B., Szymszal, J. (2015). Generation gap management in restructured metallurgical enterprises in Poland. *International Journal of Management and Economics*, *No. 47, July-September,* 107-120.
18. Gajdzik, B., Wolniak R. (2022b). Smart Production Workers in Terms of Creativity and Innovation: The Implication for Open Innovation. *J. Open Innov. Technol. Mark. Complex*., *8,* 68. Retrieved from https://doi.org/10.3390/joitmc8020068.
19. Gajdzik, B., Grabowska, S., Saniuk, S. (2021a). A Theoretical Framework for Industry 4.0 and Its Implementation with Selected Practical Schedules. *Energies*, *14(4),* 1-24, 940. Retrieved from https://doi.org/ 10.3390/en14040940, doi: 10.3390/en14040940.
20. Gajdzik, B., Wolniak, R. (2022a). Influence of Industry 4.0 Projects on Business Operations: Literature and Empirical Pilot Studies Based on Case Studies in Poland. *J. Open Innov. Technol. Mark. Complex., 8,* 44. https://doi.org/10.3390/ joitmc8010044.
21. Gajdzik, B., Sroka, W. (2012). Analytic study of the capital restructuring process in metallurgical enterprises around the World and in Poland. *Metalurgija*, *51(2),* 265-268.
22. Gölll, M., Gracel, J. (2017). Przemysł czwartej generacji – wyzwania dla badań w kontekście międzynarodowym. *KNUV, 1(51).*
23. Grabowska, S. (2022). *Modele biznesu 4.0. Architektura, tworzenie wartości, ocean konkurencyjności i efektywności.* Toruń: TNOiK, ISBN 978-83-7285-982-2.
24. Grabowska, S., Saniuk, S. (2022). Development of Business Models in the Fourth Industrial Revolution: Conditions in the Context of Empirical Research on Worldwide Scope Companies Located in Poland. *J. Open Innov. Technol. Mark. Complex*., *8,* 86. https://doi.org/ 10.3390/joitmc8020086.
25. Grebski, M.E., Gajdzik, B. (2022). Psychological safety of employees (necessity or option). *Zeszyty Naukowe Politechniki Śląskiej, Seria Organizacja i Zarządzanie, 157,* 145-155. DOI:10.29119/1641-3466.2022.157.9.

26. Greengard, S. (2015). *The Internet of Things.* Cambridge-London: MIT Press.
27. Hermann, M., Pentek T., Otto, B. (2015). Design Principles for Industrie 4.0 Scenarios. A literature review. *Working Paper, No. 01.* Technische Universität Dortmund Fakultät Maschinenbau. Retrieved from: http://www.iim.mb.tu-dortmund.de/cms/de/forschung/Arbeitsberichte/Design Principles-for-Industrie-4_0-Scenarios.pdf.
28. Hwang, M.-H., Rau, H. (2006). Development of strategies for shortening supply chain and demand chain. *Human Systems Management, 25(4).* DOI: 10.3233/HSM-2006-25404.
29. Kagermann, H., Wahlster, W., Helbig, J. (Eds.) (2013). *Recommendations for implementing the strategic initiative Industrie 4.0: Final report of the Industrie 4.0*. Working Group: Industrie 4.0: Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution, VDI-Nachrichten, Acatech-National Academy of Science and Engineering: München, Germany. Retrieved from http://forschungsunion.de/pdf/industrie_4_0_final_report.pdf, 2022.06.20.
30. Kuhn, A. (2015). On the way towards Industry 4.0: Solutions from the top cluster it's OWL – Intelligent Technical Systems East Westphalia-Lippe [Auf dem weg zu Industrie 4.0: Lösungen aus dem spitzencluster it’s OWL – intelligente technische systeme ostwestfalen Lippe]. *ZWF Zeitschrift für Wirtschaftlichen Fabrikbetrieb, 110(1-2),* p. 8.
31. Kulvatunyou, B., Ivezic, N., Srinivasan, V. (2016). On Architecting and Composing Engineering Information Services to Enable Smart Manufacturing. *J. Comput. Inf. Sci. Eng. 16*(*3*).
32. Resman, M., Pipan, M., Šimic, M. (2019). A new architecture model for smart manufacturing: A performance analysis and comparison with the RAMI 4.0 reference model. *Adv. Prod. Eng. Mang*.
33. Rüßmann, M., Lorenz, M., Gerbert, P., Waldner, M., Justus, J., Engel, P., Harnisch, M. (2015). *Industry 4.0. The Future of Productivity and Growth in Manufacturing Industries*. The Boston Consulting Group (Issue April). Retrieved from: http://image-src.bcg.com/Images/BCG-Przemysl-4-PL_tcm78-123996.pdf.
34. Santos, C., Mehrsai, A., Barros, A.C., Araújo, M., Ares, E. (2017). *Towards Industry 4.0: an overview of European strategic roadmaps.* Manufacturing Engineering Society International Conference, MESIC 2017, 28-30 June 2017, Vigo (Pontevedra), Spain.
35. Schwab, K. (2016). *The Fourth Industrial Revolution*. Cologny, Switzerland: World Economic Forum. Przekład na język polski: A.D. Kamińska. Czwarta rewolucja przemysłowa (2018). Publikacja powstała przy współpracy firmy Deloitte. Warszawa: Wydawnictwo Studio Emka.
36. Senn, C. (2019). *The nine pillars of Industry 4.0.* Retrieved from: https://www.idashboards.com/ blog/ 2019/07/31/the-pillars-of-industry-4-0/, 2019.02.07.
37. Sniderman B., Mahto, M., Cotteleerm, M.J. (2016). *Industry 4.0 and manufacturing ecosystems Exploring the world of connected enterprises.* Deloitte Development LLC, pp. 1-24, Retrieved from: https://www2.deloitte.com/content/dam/insights/us/articles/

manufacturing-ecosystems-exploring-world-connected-enterprises/DUP_2898_ Industry4.0ManufacturingEcosystems.pdf.

38. Soldaty, A. (2018). Droga do urzeczywistnienia wizji Przemysłu 4.0. *Napędy i Sterowanie*, *6,* 74-79.
39. Wang, S., Wanm J., Li, D., Zhang, C. (2016). Implementing smart factory of Industrie 4.0: an outlook. *International Journal of Distributed Sensor Networks*, *12(1),* 3159805.
40. Wiesmüller, M. (2014). Industrie 4.0: surfing the wave? E&I *Elektrotechnik und Informationstechnik*, *1*.