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ANALYSIS OF THE USE IN POLISH INDUSTRY OF MODERN TECHNOLOGY RESOURCES AS TOOLS FOR BUILDING SMART STRUCTURES

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This paper presents the enterprise as a cyber-physical system creating the new reality of the fourth industrial revolution. An explanation of the concept and essence of Industry 4.0 and a brief characterization of its key components are the starting point for a presentation of the cyber-physical system as an intelligent structure. A model of the cyber-physical system in the form of a platform consisting of hardware and software is presented. The description of the structure of an intelligent system inspired the author's concept of the architecture of such a system. In the following part of the article, the importance of identification technology and communication between industrial objects is presented as an essential element of the modern digital industry. Artificial intelligence technology is important in the development of cyber-physical systems to solve the complex problems of modern industry. The research problem concerned the issue of the use of modern digital technologies in Polish enterprises as a basis for building intelligent structures. The subject of the research was selected issues related to digital technologies used in contemporary enterprises and their impact on the functioning of organizations. The aim of the study was to provide knowledge on the type and level of modern technology resources and business solutions used. The analysis of the results of the survey made it possible to determine the level of preparedness of enterprises for cyber-physical systems. Moreover, the findings indicated the varying degree of use of modern digital technologies by enterprises.

Keywords: Industry 4.0, cyber-physical system, intelligent structures, modern technologies in Polish industry

1. INTRODUCTION

Many technical and technological innovations that have been introduced through the evolution of industry have become breakthroughs and initiated revolu-

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tionary changes in industry. Such new solutions have been associated with increased efficiency, productivity and production efficiency, machine efficiency, reduced manufacturing costs, and the ability to produce a diverse range of products and flexibly change production profiles. The Fourth Industrial Revolution is referred to as a digital transformation, changing production methods and thereby enabling products to be precisely tailored to customers' needs. Thanks to the development of IT systems, communications, mobile robotics and automation, it has become possible to digitize industrial facilities. The new industrial reality is characterized by artificial intelligence that helps create intelligent networks of facilities and intelligent process management with the interaction of real and virtual worlds.

Indeed, the fourth industrial revolution is changing the way manufacturing processes are viewed by moving them to virtual reality and the free and autonomous exchange of data between industrial facilities. Cyber-physical systems, the Internet of Things and smart factories implemented and networked together form a new, coherent whole.

The research problem presented in this article concerns the issue of the use in Polish enterprises of modern digital technologies, which are the basis for building intelligent structures. The research focused on selected issues related to the digital technology used in modern enterprises, as well as on information and communication systems and their impact on how organizations operate. The purpose of the research was to provide knowledge about the type of modern technologies and business solutions used and the level of these resources. The scope of the research included collection of empirical data, presentation of the results, analysis of said results, and the synthesis and development of conclusions. For the purpose of the analysis, a questionnaire was used containing statements (research theses), which experts responded to on an imposed five-point scale with varied content, thus determining their level of approval, degree of use, and needs. The survey results indicated that Polish enterprises used modern digital technologies to a varying degree. Moreover, although there was some commitment to their use, there were still many companies that did not fully exploit the potential of these technologies.

2. THE CONCEPT, ESSENCE AND COMPONENTS OF INDUSTRY 4.0

The concept of Industry 4.0 is related to a strategic project supported by the German government promoting the computerization of manufacturing processes. The concept of Industry 4.0 was used officially for the first time at the Hannover Fair in 2011 (Schwab, 2018). In 2013, work began on a research project in Germany to identify measures that would define the basic principles of fully automating the factory. The work resulted in recommendations on the implementations required to reach the level of the so-called Smart Industry (Siemieniak, 2021).

Industry 4.0, in a general sense, is the integration of machinery, equipment, industrial facilities, systems and processes, and the introduction of changes in production processes that will increase the efficiency of the manufacturing process and allow for flexible changes in the product mix. This includes technology as well as new work methods and the new role of the worker in industry (Piątek, 2017).

The term Industry 4.0 thus means bringing the real world of production facilities into one form, i.e. combining all the elements into one whole with the virtual world of the Internet and information technology (IT). People, industrial facilities and IT systems exchange information automatically in real time. This exchange takes place both within the enterprise and in the various IT systems operating within the enterprise. Industry 4.0 encompasses the complete value chain from placing an order and supplying materials and components for production, to shipping the finished product to customers and after-sales services. It is a concept that represents the complex process of the technical, technological and organizational transformation of an enterprise. It includes the integration of the value chain, implementation of new business models and digitization of products and services. The implementation of such solutions is made possible through the use of modern digital technologies, the use of data resources, the provision of networked communication, and the cooperation of industrial facilities and people (Siemieniak, 2021).

Increasing customer expectations and fierce competition pose two major challenges for industry: the need to continuously improve production efficiency and to produce short runs of products designed to meet individual customer needs. The flexibility of production systems is assumed to be one of the main effects of the new industrial reality. The development of Industry 4.0 sets in motion activities oriented toward the computerization and digitization of production. Cyber-physical systems (CPS) are currently being developed, which will contribute to the emergence of smart factories. Thanks to networking, machines, equipment and other objects in the production process communicate with each other and make autonomous decisions. This results in the integration of man, machine and process. Interaction and interdependence in such a system takes place between machines, machines and people, as well as between the various stages of production. This contributes to an improvement in the flexibility of the supply chain and an increase in the efficiency and speed of the manufacturing process.

The emergence of this modern industrial reality is intensifying the development and use of digital technologies. One of the fundamental ones, without which cyber-physical systems would not exist, is the Internet of Things (IoT), through which huge amounts of data on the status and condition of machines, equipment, work-in-progress, inventories, etc., are transmitted. The new form of communication between process elements, in which the digital and real world are connected to each other, enables machines, products at various stages of processing, systems, and people to exchange digital information via Internet protocol. Smart sensors with built-in systems for individual identification of production process elements and data processing systems improve the quality of communication and interaction. Advanced data processing methods are therefore required, Big Data analysis techniques are being developed for all aspects of product development and production, as well as Cloud Computing techniques with high dynamic response. The security of the data transmitted and processed on the network is linked to the development of cyber security. Modern solutions provide secure communication and identification, as well as management access to devices, systems and processes. To the technologies that complete the main system architecture of modern industry, we can add advanced simulation, virtual and augmented reality, additive (3D) printing and the full integration of enterprise IT systems (Siemieniak, 2021).

As Kuźniar (2019) noted as regards the fourth industrial revolution, it can be said that the digital industry is driven by, among other things, an increase in the amount of available data and the analysis of this data, the use of mobile connectivity to transfer data from devices, and the automation and robotization of production processes.

The key components of a systemic view of Industry 4.0 are cyber-physical systems, the Internet of Things, the Internet of Services and smart factories.

Thanks to sensors and actuators mounted on industrial objects, cyber-physical systems (CPS) connect the physical world with the virtual world, where information is processed based on a mathematical representation of real objects (Furmanek, 2018).

Meanwhile, the Internet of things (IoT) is a dynamic global network of physical objects, systems, platforms, and applications capable of communicating and transmitting data and sharing intelligence amongst themselves, the external environment, and people (Furmanek, 2018).

The Internet of services (IoS), on the other hand, is used to flexibly build a value network by dynamically configuring services selected from a variety of resources made available on the network (Furmanek, 2018).

Finally, smart factories are treated as a target solution to the Industry 4.0? concept. These are factories in which cyber-physical systems communicate with each other via the Internet of Things, and assist humans and machines in carrying out tasks through the Internet of Services. They monitor physical processes and create virtual copies of the real world and are also capable of making decentralized decisions (Furmanek, 2018).

3. THE CYBER-PHYSICAL SYSTEM AS AN INTELLIGENT STRUCTURE

In the literature, the term cyber-physical system (CPS) is complex and ambiguous. In short, it is a combination of elements such as hardware, software and communication. Intelligent machines work together by communicating and transmitting information. The essence of a CPS system is the control of enterprise processes using a network of sensors, as well as the remote monitoring of processes using a global network.

The cyber-physical system enables efficient coordination of factors and means of production using information systems and provides unrestricted access to distributed industrial data (Kamiński, 2018).

Smart structures include industrial facilities that make autonomous decisions and have the ability to communicate globally. This involves the emergence of complex and dynamically changing organizational structures that provide new levels of efficiency with little human input. Objects that are part of cyber-physical systems are characterized by a high degree of automation and computerization, as well as the use of advanced artificial intelligence algorithms (Iwański, 2017).

Cyber-physical systems combine two areas: object-oriented (machines, processes) and computational. Their task is to map in virtual reality the physical objects that are subject to monitoring, control and steering. Such mapping is intended to improve the implementation of feedback. Each system comes in the form of an embedded system, that is, a computer system (processor, memory and peripherals) that performs a dedicated function within a larger mechanical or electronic system embedded as part of a complete device. In embedded systems, the components that implement computing are of great importance. CPS solutions are used in the implementation of cyber-manufacturing systems (CMS), which support the manufacturing process based on data analysis using Industrial Internet of Things (IIoT) technologies (Pizoń, 2019).

The cyber-physical system works based on a process of continuous detection and localization of signals from the industrial sensor network. Control of the manufacturing process is carried out by automatically triggering the relevant technological operations by means of electrical, pneumatic, and hydraulic devices. Manufacturing processes are supervised by specialized IT systems equipped with intelligent decision support modules based on expert knowledge bases, as well as forecasting functions. To date, MRP/ERP class information systems have proven themselves in the framework of computerized process support in the area of a single enterprise. In accordance with the paradigm of the Industry 4.0 concept, cyber-physical systems operate in a virtual and distributed environment, which creates opportunities for interoperability within a group of independent enterprises integrated in the manufacturing process (Kamiński, 2018).

Cyber-physical systems are characterized by (ibidem):

- interoperability (cooperation on different, mutually incompatible platforms),
- intelligence (the use of artificial intelligence methods, techniques and tools),
- autonomy (automation of control processes using heuristic models, decision rules and machine learning techniques),
- flexibility (functional parameterization of controllers),

– openness (the exchange of data between different, mutually incompatible industrial automation systems, robots and computer applications, forming a complex production system).

CPS solutions related to industrial production use the term cyber-physical production systems (CPPS), in which data collection and processing occurs across the value chain, encompassing production assets, warehouse systems and supplier networks. CPPS are defined as production systems that contain a large number of embedded sensors and actuators, and software for collecting, analyzing and storing information. Such information is exchanged between CPPS components through standardized communication interfaces, but also becomes available for human use in operational or maintenance activities (Soldaty, 2016).

Smart structures provide a number of organizational benefits, among which the following can be considered the most important for the running of a modern enterprise (Farmacom, 2023):

– they provide complete and detailed information about the state of the production process and the condition of the industrial facilities, which increases the predictive capabilities and speed of response to machine failures and problems in the process;
– they allow the scheduling of production according to the resources available (machinery, inventory, or inter-operational stock);
– they improve the efficiency of the most important logistics operations related to the supply chain, warehouse management, and internal transport;
– they eliminate the loss of working time in the production process related to machine downtime, resulting from delays in the delivery of material or components;
– they improve resource allocation thanks to their ability to plan and allocate dynamically;
– they optimize the size of inter-operational warehouses, thereby reducing the size and cost of work-in-progress inventories;
– they reduce the number of logistics operations to the minimum necessary.

The huge amount of data and information, its variability over time and the dynamics of the relationships exceed the analytical abilities of humans, resulting in problems with the management and control of processes in the enterprise. Significant support in this area is seen in skillfully designed and efficiently functioning cyber-physical systems based on process data, processed in real time, and algorithms using artificial intelligence (AI) models applied in machine learning and deep learning.

Cyber-physical systems take the form of a platform, that is, a combination of hardware and software. Their main task is to improve how the production system (manufacturing, auxiliary, and service processes) operates in terms of the efficiency, productivity and reliability of the industrial facilities, as well as to reduce logistics and internal transport costs.

The architecture of the intelligent system is based on three layers: physical, cyber and communication. The basis of the system's operation is data from physical industrial objects, both those performing technological operations (lines, machines) and auxiliary objects (handling robots, conveyors, sensors, and other equipment). This layer also includes data on internal means of transportation operated by operators (forklifts) and autonomous vehicles (transport robots). The third group in this layer includes data on warehouses (material, components, finished products, and auxiliary materials) and data on the location and quantity of material and components in the process. Therefore, it can be assumed that all the physical data sources providing information on the state of the production system should be considered components of the physical layer (Farmacom, 2023).

Elements of the physical layer have their reflection (digital image) in the cyber layer, to which they send data via the communication layer. Each object has its virtual model on the platform in the form of a digital twin, which reads the parameters of the process, machines, equipment, industrial facilities, and data from the systems supporting, controlling and managing the processes. Transportation models map the means of internal transportation, while warehouse models reflect the quantity and location of the material and components in the production process. The modules that collect, store, archive and process the data are fundamental to the architecture of this layer's cyber-physical system. The most essential module of the cyber-physical layer is the module that analyzes the data collected, maintaining autonomous control of the parameters and settings and making adjustments not only for critical processes, but also for individual machines, equipment, and objects (Farmacom, 2023).

The communication layer consists of computer technologies and solutions (routines, protocols, algorithms, and conditional, iterative, and logical instructions) that allow data transfer between programs and subroutines. Data transmission from the physical layer to the cyber layer is carried out by connecting objects to an Ethernet network, which provides extremely stable and fast data transmission. For this reason, it is used in computer systems that support and control the processes of material requirements planning (MRP), enterprise resource planning (ERP), manufacturing execution (MES), warehouse management (WMS), supervisory control and data acquisition (SCADA). An additional communication medium is a wireless network (WiFi, Bluetooth) used in areas where there is no data interference and transfer speed is not a priority. Real-time monitoring of enterprise processes requires reliable detection, transmission, and recording systems, and a stable and fast network infrastructure. The right IT solutions are the basis for proper process management within enterprises (Farmacom, 2023).

The author's concept of a cyber-physical system is illustrated in Figure 1. The standard three-layer architecture (physical, cyber-physical and communication) has been expanded with additional layers entering into relationships, interdependencies, and functional and task linkages, extending and complementing the basic model. The layer of traditional decision-support IT systems has been expanded to

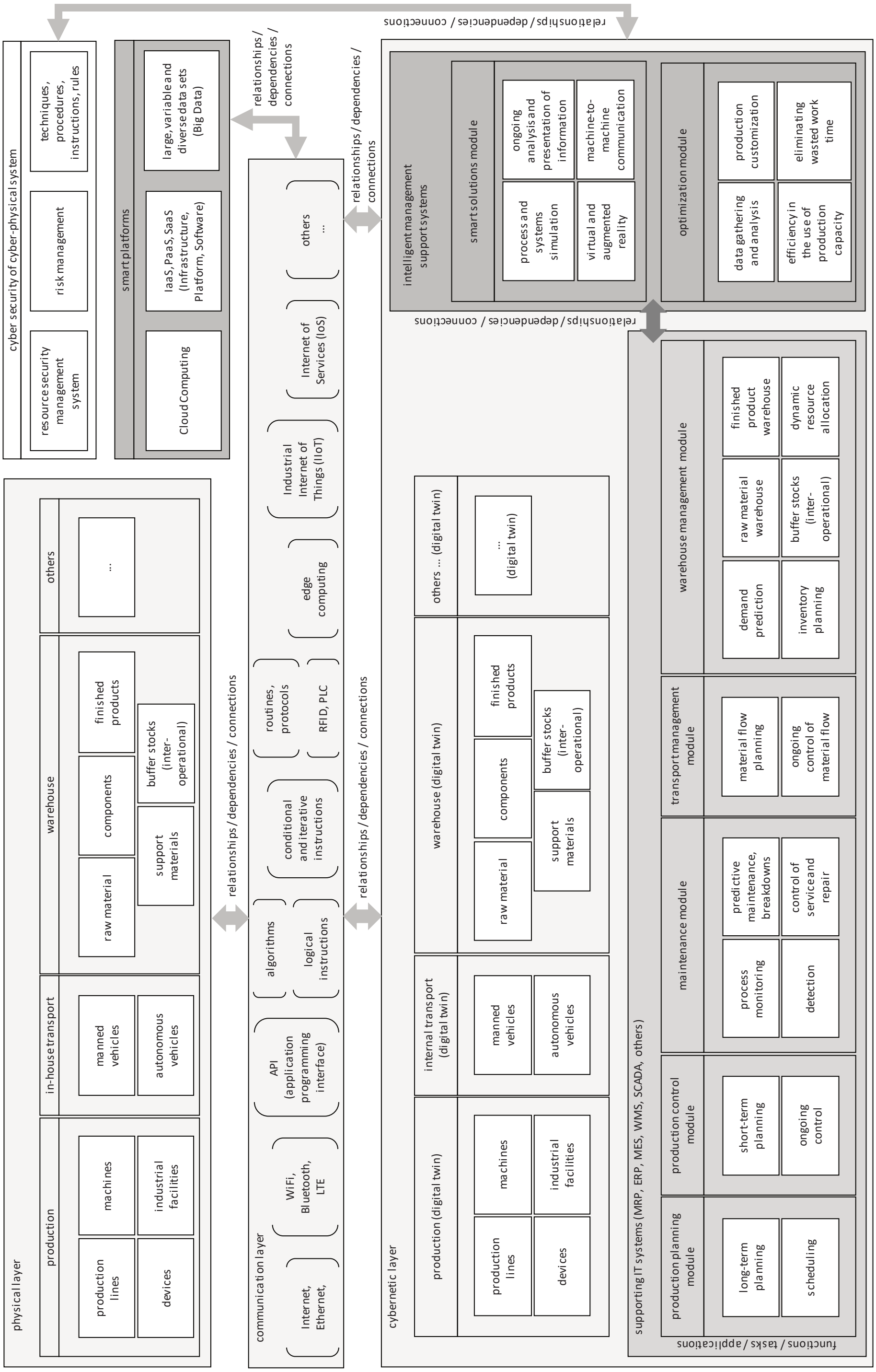

Fig. 1. Concept of a cyber-physical system

include a layer of intelligent management support systems at various levels with a module of digital technologies for simulating processes and systems, the possibility of using virtual and augmented reality, and techniques to control communication between machines and industrial facilities. An important element is the ability to conduct real-time data analysis with advanced tools for creating reporting systems. Due to the large amounts of data generated by the monitoring, surveillance and detection systems, recorded by various applications, and therefore recorded in different formats, with different content, it is necessary to transfer data to the cloud, where, using modern cloud solutions, it becomes possible to process dynamically changing data into useful information.

The growth of digital industry and the use of modern information technology (IT) in enterprises is driving a growing interest in the issue of cyber security since the combination of industrial facilities and IT systems in the Internet of Things (IoT) network may contribute to an increase in cyberattacks. In addition, modern industry is characterized by the use of operational technology (OT) systems working with information technology (IT) in the production process, which increases the possibility of adverse events (incidents) occurring. Therefore, organizational units dealing with operational technology within enterprises should expand their competence by cooperating and coordinating with information technology units in order to increase the security of resources. For this reason, the cyber-physical system concept also includes a cyber-security layer.

4. OVERVIEW OF SELECTED MODERN TECHNOLOGIES

Digital technologies play a key role in manufacturing processes and management. Firstly, automation and robotization eliminate human error, increase productivity and reduce manufacturing time. Meanwhile, the Internet of Things connects manufacturing equipment and systems in one overall network, enabling the real-time monitoring of manufacturing, process optimization and remote control. Furthermore, data analytics enables the identification of trends, process optimization and better business decision-making. Digital manufacturing uses advanced technologies such as 3D printing for faster prototyping and customized production. The integration of IT systems and platforms enables better communication between different elements of the production process, as well as easier system management and control. Moreover, digital logistics and supply chain management allow the optimization of transport and warehousing. Digital technologies support innovation, productivity growth, production flexibility and competitiveness. The aforementioned aspects of modern industry are closely related to the empirical research presented in this article, therefore a brief overview of the importance of selected modern technologies is provided below.

The Industrial Internet of Things (IIoT) is one of the most important technologies in the new industrial reality. Digital transformation has become a necessity for organizations that care about increasing production efficiency, ensuring an efficient flow of data and information, and improving process management. Today's companies use the technology of systems for supervising, monitoring, or extracting data from the production system, systems for resource management, and maintenance. With personalized IIoT software and services, it is possible to easily access data, and feedback is sent in real time. The development of the digitization of enterprises, advanced computerization and robotization of production systems, and the connection of industrial facilities to a network of cyber-physical systems, forming smart factories, contributes to the creation of new opportunities for enterprises: algorithmic and programmable products and services related to cloud computing and the use of artificial intelligence. It becomes possible to collect customer feedback that may influence the design of products, thereby achieving new values for customers. For the enterprise, this opens up the possibility of creating new business opportunities and strategies (Dyess, 2019).

The mechanization and automation of processes eliminates the need for employees to perform repetitive tasks such as operating machines and equipment. Robotics combined with IIoT enables computers to make autonomous, decentralized decisions, and real-time process monitoring makes it possible to automatically make adjustments to processes and machine parameters, thus helping to improve quality and increase productivity. In addition to participating in analytical processes, IIoT enables the monitoring and detection of upcoming problems in the area of maintenance and repair planning. In this way, it supports the concept of predictive maintenance, thus increasing the reliability of machines and equipment and their availability, as well as reducing the cost of unplanned downtime (Dyess, 2019).

The automatic identification of physical objects (machines and equipment) in the network is carried out using RFID (Radio-Frequency Identification) technology. With the help of sensors, it is possible to automatically detect the state of the equipment, read out technological parameters in real time, transmit control signals, exchange messages, and cooperate with other devices connected via the IIoT wireless network. RFID, which is a technology that allows the reading and transmission of data, is used in industrial, manufacturing, logistics, and warehouse processes. Thanks to the development of digitization and robotization technology, it is becoming the standard for wireless identification and communication between objects. RFID helps to automate processes, identify products, machines, and equipment, improve control, increase the efficiency of tasks performed and synchronize manufacturing processes carried out in different locations (RFID Polska, 2023).

Of significant importance in the development of modern Industry 4.0 solutions is artificial intelligence (AI) technology, which enables machines to learn and solve complex problems. Artificial intelligence systems differ from other AI systems in that the mechanism of the problem-solving module is designed to resemble the work of the human brain. Artificial intelligence deals with the creation of models of intelligent behavior and programs and systems that simulate intelligent behavior. A special area of interest for AI is problems that are not effectively algorithmized. This means that there is no sequence of clearly defined actions necessary to perform a certain type of task, therefore it is very difficult or impossible to represent them in the form of a flowchart. The concept of artificial intelligence is defined as the ability of a system to correctly interpret data from outside, learn from it, and use the knowledge to perform specific tasks and achieve goals through flexible adaptation (Russell, Norvig, 2023; Boden, 2020; Kaplan, Haenlein, 2019; Flasiński, 2011; Rutkowski, 2009; Zieliński, 2000).

The use of artificial intelligence (AI) models in industrial settings brings many benefits. By combining artificial intelligence technology with the industrial Internet of Things, it becomes possible to apply advanced techniques for production data analysis, machine learning and the supervision of the automation and robotization of manufacturing, thus increasing the efficiency of processes, as well as improving product quality and the efficiency of predictive actions. It is important to optimize not only production processes, but also other processes that affect the functioning of the organization and that result from the analysis of data from various sources in various forms. The results of the analysis carried out by artificial intelligence provide information on the demand for finished goods, market trends, as well as warehouse and inter-operational stock. They also control the course of the production process in real time.

Cloud technology (cloud computing) makes it possible to perform complex calculations and analyze data from machinery, equipment and other industrial facilities outside the company's servers. It also enables the use of algorithms based on artificial intelligence, which is mainly associated with the robotization of industry. Until now, robotic devices have been programmed by engineers to perform specific tasks. The current technological level allows robots to learn how to perform production tasks on their own, as well as how to interact with other robots, industrial objects and humans. To communicate between robots, technologies are needed that collect, transmit, process and analyze data on the one hand, and provide valuable feedback on the other (Siemieniak, 2021).

Cloud computing offers many useful tools and services that can be used to store and analyze data from an organization’s processes and systems. The costs of using high-performance cloud technologies are lower than building and maintaining in-house analogous IT systems and applications needed to process data. Cloud services are characterized by high availability and performance, flexibility, as well as scalability, and can provide a high level of data security and protection.

The applicability of artificial intelligence systems in machine technology is related to machine learning and deep learning technology. One might say that artificial intelligence is an object's ability to simulate human intelligence, therefore it gives an object the ability to operate without being programmed by a human. Deep learning allows objects to self-learn based on their own experience (Siemieniak, 2021).

Machine learning is an area of artificial intelligence related to algorithms that improve automatically through experience. Machine learning algorithms build a mathematical model from sample data, known as, training data, to make predictions or decisions. The learning and refinement processes are not pre-programmed. Algorithms are trained to find patterns and correlations in large data sets, to make the best decisions and to make predictions based on the results of the analysis. Machine learning algorithms are used in areas where it is difficult or infeasible to develop traditional algorithms to perform necessary tasks. The system's learning process aims to produce results based on fragmented knowledge, enable refinement, create new concepts and make inductive inferences. Systems using machine learning processes are most often used for analyzing large data sets, searching for relationships between data in order to synthesize information according to set criteria. In addition, machine learning is used when it is necessary to adapt the system to the environment through dynamic modification, allowing it to operate efficiently under changing conditions, such as in production control systems and robotics (SAP Polska, 2023; Sibiz.pl, 2023).

Deep learning is a subcategory of machine learning. It allows the system to think on its own and learn, as it mostly proceeds without the need for direct human supervision. Therefore, we can say that deep learning is a product of the evolution of the machine learning system and it consists of more advanced algorithms, using artificial neural network systems. The deep learning system runs multiple layers of neural networks, providing more accurate results (SAP Polska, 2023; Sibiz.pl, 2023).

Computer-aided design (CAD), computer-aided manufacturing (CAM) or computer-aided engineering (CAE) systems play a key role in modern enterprises. They allow the precise design of products, machine elements or component systems in three-dimensional (3D) technology. This technique allows the designed component to be visualized and possible changes to be made easily before it is physically manufactured. They are also used to design manufacturing processes, optimize them, and simulate changes. Moreover, they allow the simulation and analysis of tests and technical parameters to optimize engineering processes. They share and access design data, communicate in real time and allow changes and progress in design work to be tracked. In modern industry, enabling systems work with other technologies and IT systems to easily customize products and offer personalized solutions.

The essence of building cyber-physical systems in an enterprise is the ability to represent models of real objects or processes in a virtual environment in three-dimensional (3D) form. Such a process, called reverse engineering, requires the use of specialized scanning tools and specific engineering methods. The parametric and surface data collected in this way is processed in a CAD system, creating a complete virtual image of the object or process together with documentation. Reverse engineering technology is used when there is a requirement for a component and no technical documentation exists. It allows information about the design of the component to be obtained, technical analysis to be carried out and modifications to be made. In the case of the representation of manufacturing processes in a virtual environment, this technology enables changes, improvements, optimization analyses and simulations to be made before implementation. The digital representation of real objects in a CAD system allows a three-dimensional (3D) print form to be made with high precision. This is one of the forms that provides the basis for the creation of personalized products.

The digitalization of production processes and the networking of industrial facilities are the drivers for the creation of cyber-physical systems. This becomes possible through the use of modern machinery, equipment, industrial facilities and technologies that allow the implementation of innovative manufacturing methods. The introduction of modern solutions makes it possible to develop organizations and move to a higher technological level. An exemplification of the above is AVG (Automated Guided Vehicles) robots which are self-propelled transport trucks used for logistics purposes in closed spaces such as production halls and warehouses. They move along a set path, transporting materials for production and finished goods to the warehouse. They use RFID radio-frequency identification technology to communicate with their surroundings, while camera and scanner systems ensure collision-free transport, obstacle avoidance and loading of goods. Often, these vehicles are connected remotely to warehouse and logistics management IT systems within the company, making it easier to monitor the status of inter-operational warehouses, increasing the efficiency and effectiveness of internal transport.

In addition, intelligent structures within an organization mean that people and industrial facilities work together to transmit real-time information about all stages of the production process. Effective process management and control involves the use, and often the combination and cooperation, of modern methods and tools. Building modern solutions would not be possible without the support of information technology (IT) systems, as well as planning, control, and process monitoring systems. An example of a system supervising the technological and production process in a company is SCADA (Supervisory Control And Data Acquisition). The main purpose of its application is to increase the efficiency of the manufacturing process with the real-time collection of measurement data from machines and equipment, and their visualization, as well as the archiving and control of processes by setting appropriate parameters. It is also possible to immediately detect errors, set alarms and send information to operators. The essence of the system's operation is based on cooperation with the automation components implemented in the process. The system operates in the equipment chain, between the control, measurement and execution elements and the machine operator, playing a superior role. In modern industry, the SCADA system is often integrated with other IT systems for planning or process control (e.g. ERP) and with analytical systems. It centralizes the control of distributed systems and processes and provides comprehensive management of the information and communication systems infrastructure.

The MES (Manufacturing Execution System) uses information technology, software and automation elements to collect data from the production process in real time. The essence of the system is to monitor and manage processes at an operational level. The MES interfaces with various IT systems for resource planning, process control systems, and production line facilities, among others. The most important tasks of the system include activities related to production planning and scheduling, controlling the allocation of resources, monitoring production progress, managing the warehouse of raw materials, finished materials and inter-operational warehouses, as well as tracking production batches and optimizing inventories. The MES system monitors and collects in real time a wide range of data from the production process concerning the technological parameters of the manufacturing process, process performance, quality parameters, material consumption level, machine condition, and failures. Data from the operational level is analyzed in the system and transformed into useful information generated in the form of reports for operators, specialists and management. This makes it possible not only to take effective operational measures, but also to monitor key performance indicators (KPIs) and identify areas in the company where improvements need to be made.

The E-Kanban system is used to control information in the manufacturing process of a modern company. It regulates the movement of materials between technological operations. It is an electronic form of the Kanban system, in which sheets of paper have been replaced by an electronic communication and data transfer system. The e-Kanban system has information about materials in the production process, their location, quantity and level of inter-operational warehouses. Information on material requirements is generated automatically on the basis of electronic consumption data. E-Kanban can collaborate with other IT systems for material requirements planning, which increases the efficiency of logistics process management in the company. It also makes it possible to carry out optimization analyses in the areas of material requirements, internal transport, reduction of working time losses (wastage), and improvement in process efficiency.

5. DETERMINANTS AND IMPLICATIONS OF SMART STRUCTURES

The essence of modern industry is the interconnection of machinery, equipment and industrial facilities into a single network of the industrial Internet of Things, the mobility of equipment, the use of the functional capabilities of digital sensors and controllers in production systems, and the use of the computational potential of artificial intelligence models in the service of multifaceted data analysis, processing it into useful information and supporting decision-making at various organizational levels. A core component of modern industry, the Internet of Things enables the integration of cyber-physical systems, the design, supervision and control of high-tech manufacturing systems, the development of robotization, and the efficient management of enterprise systems and processes (Siemieniak, 2020).

A fundamental feature of modern digital industry is a paradigm shift in manufacturing. The changes concern not only the way the production system is managed, but also the methods of product design, delivery of the finished product to the customer, and the search for new business models. New solutions are the result of the evolution of technological systems and processes. The foundation for changes in the way enterprises operate is the merging of production lines, machines, equipment and other industrial objects into a network of the Industrial Internet of Things (IIoT); the reflection of the real world (physical layer) in the virtual world (cyber layer), the effective transformation of large amounts of diverse and dynamic data into highly useful information, advanced automation and the robotization of processes, the autonomy of industrial objects, and a new model of human-machine cooperation. Changes in the enterprise environment are also a determining factor. For a company, product personalization means moving away from the mass production model toward making individual solutions and designs. This implies a change in the manufacturing model used so far - a move away from the traditional technological route, in which each product item had a specific order for the execution of technological operations and was assigned to specific machines. The model of centralized product manufacturing is being replaced by decentralized systems, i.e. systems in which IT systems communicate (connect) the product with industrial facilities, selecting the most optimal process. The efficient flow of information from the customer to the enterprise is a new business model, based on direct contact with the buyer's market. The acquired information about customer needs allows the enterprise to respond quickly, using flexible manufacturing systems. High-tech industrial facilities and solutions, forming complex systems and processes, are proving to be extremely useful tools for creating cyber-physical systems as homogeneous intelligent structures. Technical and technological innovations imply new priorities for companies: efficient and agile machinery, highly effective production, low manufacturing costs, high quality products, diversification of product items, flexibility of changes in the production profile and the need for the ability to adapt processes to growing customer demand. Consumer behavior is determining transformation in industry in the area of manufacturing processes, management and control systems for processes and systems, logistics and labor organization (Siemieniak, 2020).

6. MODERN TECHNOLOGY RESOURCES IN POLISH INDUSTRY: RESULTS OF EMPIRICAL RESEARCH

The research problem related to the issue of the use in Polish enterprises of modern digital technologies, which are the basis for building intelligent structures such as cyber-physical systems.

The subject of the research was selected issues related to digital technology used in modern enterprises, and information and communication systems and their impact on how organizations operate.

The purpose of the research was to provide knowledge about the type and level of modern technologies, as well as the information techniques and business solutions used. Synthesizing the results of the research could help determine the degree of preparedness of enterprises to build cyber-physical systems.

The scope of the research included the collection of empirical data, presentation of the results, their analysis, synthesis, and development of conclusions.

For the purpose of analyzing the use of modern digital technologies in Polish manufacturing enterprises, a questionnaire was used containing statements (research theses), which experts responded to on an imposed five-point scale with differentiated content, thus determining their level of approval, degree of use, and needs.

The topics of the selected research theses were related to:

– the type of modern technologies used,
– the scope of use of information and communication technologies (ICT),
– the impact of ICT on the how the organizations functioned.

A group of one hundred and fifty Polish enterprises (60 large and 90 medium-sized) in nineteen industries across sixteen provinces took part in the survey. The respondents were divided into three groups: the first group consisted of CEOs, board members, owners and managing directors, the second group consisted of technical directors, and the third group consisted of managers and executives (Fig. 2).

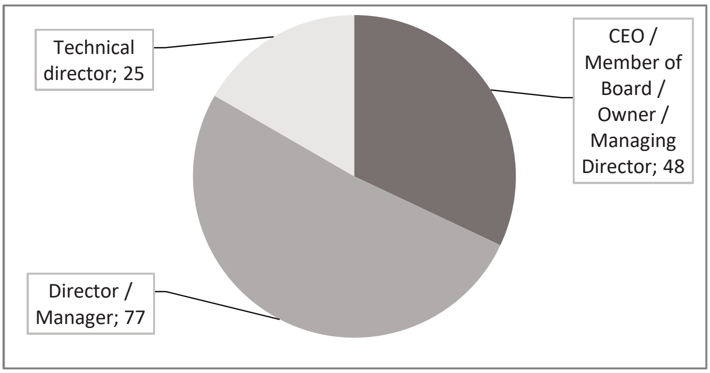

Fig. 2. Structure of respondents

A positive phenomenon, from the point of view of the issue of the use of modern technology resources in Polish industry, is the high level of activity of organizations in tracking technological changes. Almost half of the companies surveyed declared a high (40.7%) or very high (8.7%) interest in this area (Fig. 3).

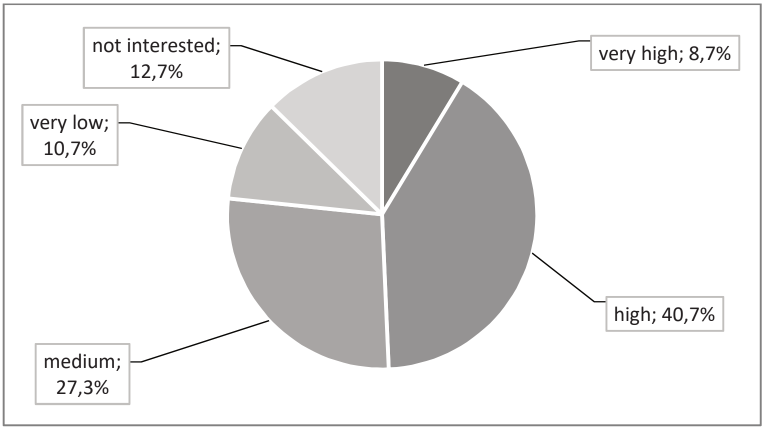

Fig. 3. Structure of interest of the management of enterprises in technological changes

Analyzing the data from the enterprises surveyed, it can be seen that 72% of the respondents showed a significant interest (41.3% high and 30.7% very high) in customer market changes (Fig. 4).

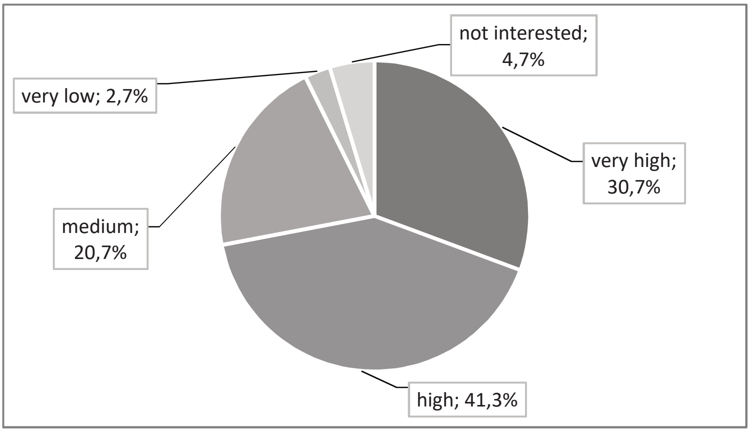

Fig. 4. Structure of interest of business executives in customer market changes

The research showed that the potential of modern technology is not fully exploited by the enterprises (Fig. 5). There was a significant number of organizations that did not use it at all or only used it to a small extent. A positive phenomenon, from the point of view of the issue under consideration, is the fact that there were enterprises that used the potential of digital technologies and IT systems to varying degrees.

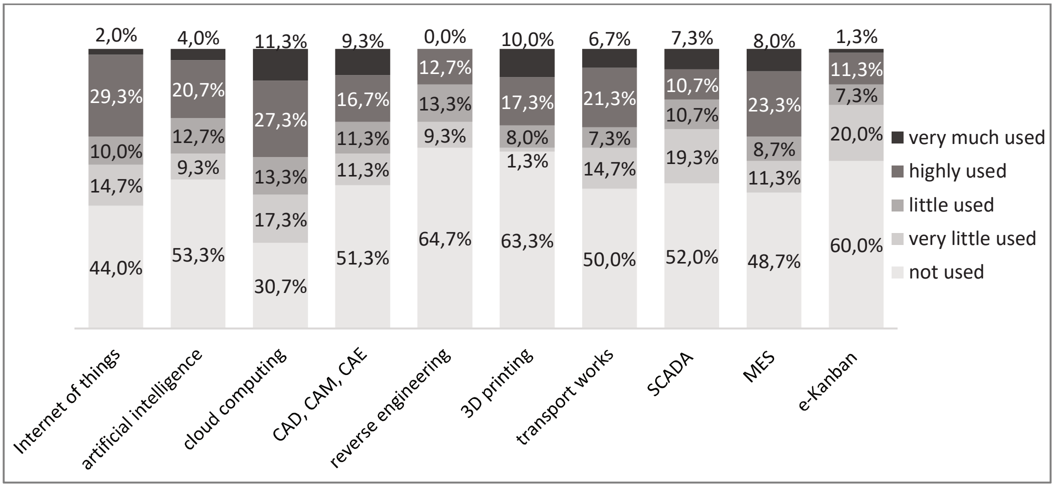

Fig. 5. Degree of use of modern technologies in enterprises

The potential for using the capabilities and functionality of Internet of Things technology in the companies surveyed was as follows: 44% of the organizations did not use this technology at all, 14.7% to a very small degree, and 10% to a small degree. The IoT is an essential tool for creating intelligent structures for the modern enterprise. The use of the functional capabilities of the Internet of Things (which 31.3% of the enterprises declared as being to a large and full extent) allows us to presume that these organizations have created conditions conducive to the implementation of modern technologies and the building of cyber-physical systems.

Less than a quarter of the enterprises fully used the functional capabilities of artificial intelligence models, and more than half did not use any artificial intelligence models as a tool to support the functioning of the enterprise.

Of the organizations surveyed that reported using cloud computing technology to varying degrees, 38.7% made full use of the available services, while more than 30% made little or no use of it. 30.7% of the companies surveyed did not use the technology in any way.

More than half of the organizations did not use design process support tools (CAD, CAM, CAE), while 26% made full use of the capabilities of this technology.

The extent to which reverse engineering technology was used was low, with 12.7% of the organizations reporting significant use of it in their operations, while 22.6% made little use of it. Almost 65% of the organizations did not use it at all.

The technology for creating three-dimensional objects (3D printing) was used in a total of 36.7% of the companies surveyed, with 27.3% declaring full use of it, while 63.3% indicated that there was no need to use it in their business.

When looking for opportunities to use transport robot technology in logistics systems, it could be seen that half of the companies did not use self-driving robots in internal transport. On the other hand, a total of 28 per cent of the organizations used modern transport fully, while 22 per cent made little use of it.

Slightly more than half of the organizations did not use a SCADA technology and production process monitoring system, 30% made little use of such capabilities, while 18% made full use of the system's potential.

Full use of information technology, software and automation elements for real-time manufacturing process data collection (MES) reached almost a third of the companies surveyed, a fifth made partial use, while almost half did not use this system at all.

The e-Kanban system was used in 40% of the companies surveyed to varying degrees of use, while 60% of the organizations did not use the system.

The analysis of the degree of use of modern technologies in enterprises also provided information on the structure of the answers given by the organizations surveyed regarding the degree of use (Fig. 6). The results indicated that a total of

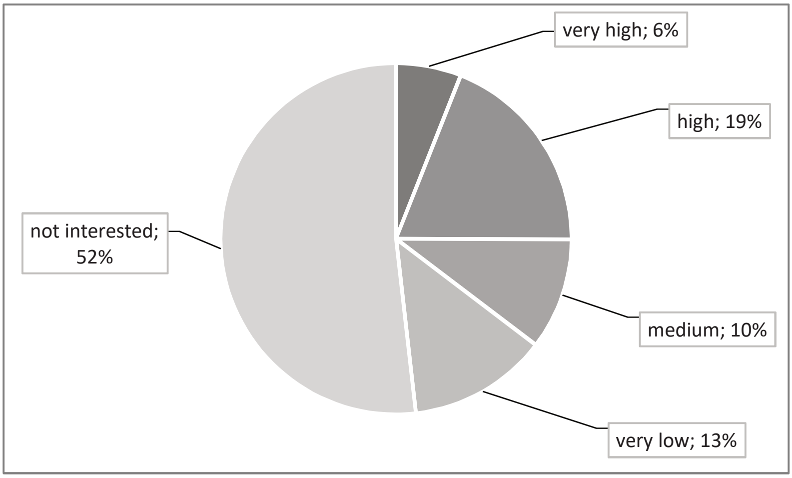

Fig. 6. Degree of use of modern technologies in enterprises

one quarter of the answers given related to the large-scale use of modern technologies by the organizations. Less than a quarter of the enterprises used modern technologies to a limited or small extent. More than half of the enterprises surveyed did not use any modern technology or at least one of them was not used at all.

The process of increasing the scope of ICT use in the enterprises surveyed varied in terms of the direction of action taken in this area. Slightly more than a quarter of the organizations declared that they were undertaking intensified implementation activities. There were some that had increased the scope of activities moderately or very little (47%). A lack of commitment was shown by 27% of the organizations (Fig. 7).

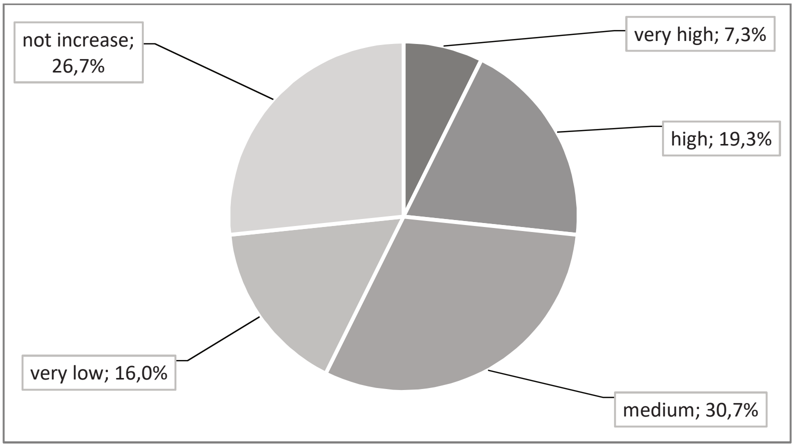

Fig. 7. Structure of intensification of ICT use in enterprises

According to the organizations surveyed, the use of ICT had a significant impact on improving economic efficiency (85%). Slightly more than two-thirds of the organizations noted the strong impact of ICT on expanding the companies' specializations. However, almost a quarter of the companies believed that the technology had no major impact in this area (Fig. 8).

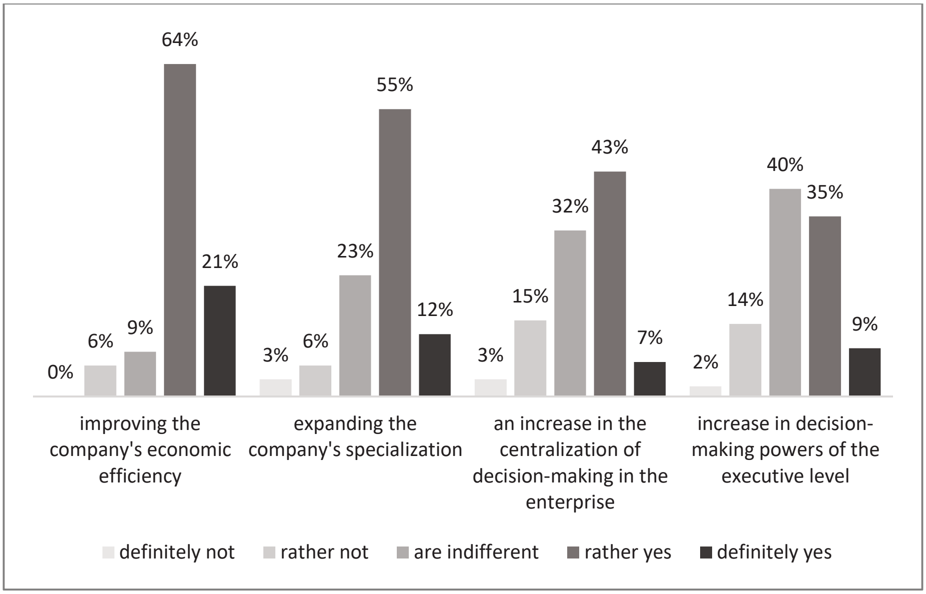

Fig. 8. Structure of impact of ICT on selected areas of business activity

Interesting findings are revealed for the topic related to the centralization of decision-making in companies: half of the organizations claimed that this process was increasing with the use of ICT, while almost a third did not notice any change.

In terms of the impact of ICT on an increase in executive decision-making powers, the companies surveyed were either indifferent to change (40%) or noted a clear increase in powers (44%).

7. CONTRIBUTION OF THE EMPIRICAL RESULTS OBTAINED TO THE DEVELOPMENT OF THEORY, PRACTICAL IMPLICATIONS AND DIRECTIONS FOR FURTHER RESEARCH

The article presents an advanced approach to the integration of modern information and industrial technologies. The concept of cyber-physical systems defines an infrastructure that enables harmonious interaction between information and physical systems. This approach extends the general understanding of the concept of implementing modern technologies in industry. The importance of artificial intelligence in control, monitoring, data analysis and prediction in the context of manufacturing processes is highlighted, indicating the growing role of artificial intelligence as a key component of modern industry. The importance of the Internet of Things in the industrial context presented in the article is consistent with the theory of using the Internet of Things in intelligent production systems.

The use of cyber-physical systems, artificial intelligence, and the Internet of Things is leading to improved production processes through automation, optimization, monitoring and remote control. By using modern technology, companies can create more flexible production systems that respond quickly to changing market needs. Moreover, intelligent IT systems enable decentralized decision-making, which improves companies' responses to market needs and makes the management process more flexible.

Directions for further research in the area of building smart industrial structures should focus on three areas: optimizing the use of modern technologies, the security of industrial systems, and technological integration. Research should focus on identifying best practices in the use of cyber-physical systems, artificial intelligence, and the Internet of Things in different areas of industry. There is a need for research on securing cyber-physical systems against cyber threats to ensure the integrity and security of data and the industrial infrastructure. An important part of building smart structures is the integration of different technologies such as artificial intelligence, the Internet of things, and cloud computing to create comprehensive and efficient cyber-physical systems.

8. SUMMARY

To run a company in the new reality, it is essential to use systems which are modern, sophisticated and technologically advanced, i.e. cyber-physical systems. These systems use artificial intelligence methods and techniques to implement the control and monitoring of production processes, for data analysis and synthesis, and for simulation and prediction. The combination of the real and digital worlds makes it possible to create an intelligent enterprise, capable of informed and autonomous decision-making, thanks to the networking of industrial facilities. The collection, transmission, processing, and sharing of data from industrial systems, processes and facilities, and their transmission to the cloud, creates new opportunities for analytics and the remote diagnostics of industrial facilities, as well as the ability to manage the operation of these facilities via the internet.

Cyber-physical systems, combining and coordinating computational and physical resources, far surpass the level of technical sophistication and functionality of solutions in the traditional enterprise in terms of adaptability to a dynamically changing environment, autonomy in decision-making, control and correction of processes, as well as efficiency, functionality, reliability and usability.

The enterprise as a cyber-physical system involves intelligent production processes, a new level of industrial communication, smart machines, advanced computing and better (easier and faster) access to data, which increases the scope, quantity, quality and resolution of available feedback, thereby allowing the knowledge base of processes to be built.

The Industrial Internet of Things (IIoT) is a general concept that refers to the use of network technology in industry, while Cyber-Physical Systems (CPS) is a technological infrastructure that enables the integration and interaction between physical components and information systems.

The high level of activity of the organizations surveyed in tracking technological change is indicative of the high level of awareness among the organizations' management of the necessity to carry out improvement and innovation activities and move to the use of advanced manufacturing processes and systems. Such intelligent cyber-physical structures and systems consist of a combination of modern information technology (IT) solutions, the use of available application tools and services from the Internet of Things, cloud analytics, the automation and robotization of an organization's manufacturing processes, and the application of artificial intelligence (AI) models to monitor, plan, control and manage objects, systems and processes in an enterprise.

The competition between companies for markets, the acquisition of new customers and the growing needs of customers contribute to a situation in which organizations initiate activities related to improving the efficiency, productivity and effectiveness of production processes. The successive stages of industrial revolutions aimed at computerization, automation and the robotization of processes and systems have contributed to better utilization of labor resources, an increase in desired process parameters and a reduction in costs, enabling the development of mass production. The challenge for today's companies is now the production of short series of products that are designed according to customer expectations. This determines the need for flexible production systems. Here, monitoring the sales market is an indispensable element of building a proper business management strategy.

In terms of the problem under investigation, i.e. the use of modern technology resources in Polish industry, it is important to combine two issues: the high interest of enterprises in technological changes, and changes in customer needs. The analysis of this data allows us to conjecture that organizations are adapting their processes and technological level to the current requirements of the consumer market, and therefore the implementation of digital solutions creates conditions for building smart structures in enterprises.

To identify the type of cutting-edge technologies used in the surveyed companies, these organizations determined the scope of digital technologies and solutions they used from a previously prepared list of ten: the Internet of things, artificial intelligence, cloud computing, IT systems supporting design and manufacturing, reverse engineering, 3D printing, transport robots, IT systems managing and controlling production, monitoring machine condition, and supporting flow control in production.

The research showed that the potential of modern technology is not fully exploited by companies. There are a significant number of organizations that do not use it at all or use it to a small extent. The reason for this may be the lack of awareness among the organizations' management of the possibility of using these technologies and the benefits gained, as well as concerns about the cyber security of industrial systems and facilities, and the costs associated with the implementation and maintenance of new technologies. A positive phenomenon, from the point of view of the issue of the use of modern technology resources in Polish industry, is the fact that there are enterprises that use the potential of digital technologies and IT systems to a varying degree, which may indicate an increased interest in their functionality, efficiency and flexibility. The use of the functional capabilities of the Internet of Things allows us to conjecture that organizations are creating conditions conducive to the implementation of modern technologies and building cyber-physical systems. A small number of organizations are fully exploiting the potential of all the technologies discussed or are only fully exploiting some technologies. However, the situation indicates a high awareness of organizations of the possibility of using modern technologies as a resource for building intelligent structures (cyber-physical systems) in order to improve the processes of planning, controlling, optimizing and managing within the enterprise.

ICT has a significant impact on the centralization of decisions in an organization, contributing to its reduction. ICT enables easy access to the information needed from different areas (organizational units), which promotes decision-making at different levels of the organizational structure, therefore there is no need to transfer information to a single decision point. The rapid exchange of information and co-operation between organizational units, the possibility to monitor the progress of project work, or access IT decision-support systems (e.g. Business Intelligence systems) promotes the decentralization of decision-making. This improves the communication process within the company and gives greater autonomy in decision-making at lower levels of the organization.

Therefore, the essence of intelligent systems in modern companies is the decentralization of operational decision-making. This process is realized in the IT systems which communicate with industrial facilities in an autonomous manner, i.e. without human involvement.

Ultimately, the degree of centralization of decision-making in an organization depends on the structure and strategy of the enterprise and on the modern IT technologies it uses.

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ANALIZA WYKORZYSTANIA ZASOBÓW NOWOCZESNYCH TECHNOLOGII W POLSKIM PRZEMYŚLE JAKO NARZĘDZI DO BUDOWANIA INTELIGENTNYCH STRUKTUR

Streszczenie

W artykule przedstawiono przedsiębiorstwo jako system cyberfizyczny kreujący nową rzeczywistość czwartej rewolucji przemysłowej. Wyjaśnienie koncepcji i istoty Przemysłu 4.0 oraz krótka charakterystyka jego najważniejszych komponentów były punktem wyjścia do prezentacji systemu cyberfizycznego jako inteligentnej struktury. Zaprezentowany został model systemu cyberfizycznego w postaci platformy składającej się ze sprzętu i oprogramowania. Opis struktury inteligentnego systemu opartego na trzech warstwach – fizycznej, cybernetycznej i komunikacyjnej – stał się inspiracją do stworzenia autorskiej koncepcji architektury takiego systemu. W dalszej części artykułu zarysowano znaczenie technologii identyfikacji i komunikacji między obiektami przemysłowymi jako znaczący element nowoczesnego przemysłu cyfrowego. Istotne znaczenie w rozwoju systemów cyberfizycznych ma technologia sztucznej inteligencji, która umożliwia między innymi przeprowadzenie procesów uczenia maszynowego, a dzięki temu rozwiązywanie złożonych problemów nowoczesnego przemysłu. Problem badawczy prezentowany w niniejszym artykule dotyczy zagadnienia wykorzystania nowoczesnych technologii cyfrowych w polskich przedsiębiorstwach stanowiących podstawę do budowania inteligentnych struktur. Przedmiotem badań są wybrane zagadnienia związane z technologią cyfrową stosowaną w nowoczesnych przedsiębiorstwach i z systemami informacyjno-komunikacyjnymi oraz ich wpływem na funkcjonowanie organizacji. Celem badań jest dostarczenie wiedzy o rodzaju i poziomie wykorzystywanych zasobów nowoczesnych technologii i rozwiązań biznesowych. Analiza rezultatów badań pozwoliła określić stopień przygotowania przedsiębiorstw do tworzenia systemów cyberfizycznych. Wyniki ankietowe wskazują na zróżnicowany stopień wykorzystania nowoczesnych technologii cyfrowych przez przedsiębiorstwa. Chociaż istnieje pewne zaangażowanie w ich wykorzystanie, wciąż jest wiele firm, które nie stosują w pełni potencjału tych technologii.

Słowa kluczowe: Przemysł 4.0, system cyberfizyczny, inteligentne struktury, nowoczesne technologie w polskim przemyśle