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COBOTIZATION AS A KEY ELEMENT IN THE FUNCTIONING OF SMART FACTORIES AND A NEXT STEP IN THE AUTOMATION OF LOGISTIC PROCESSES

Abstract

This paper aims at presenting the innovative methods of automation of manufacturing processes and their accompanying supporting processes. The author has reviewed scientific articles whose focus of study are modern technologies developed in line with the idea of Industry 4.0. The paper also includes a brief description and an analysis of the course of technological progress which has eventually led to the next industrial revolution. It also identifies the basic pillars of the functioning of the fourth industrial revolution, such as the Internet of Things, Computing Cloud and Cyber-Physical Systems, all of which simultaneously constitute the foundation of existence of Smart Factories – which should become crucial to contemporary economy. The automation of technological lines and transport systems and their robotization and cobotization have been described as phenomena leading to advanced automation of logistics processes. Smart Factories have been presented as entities that will, through the application of the aforementioned systems and technologies, lead to the achievement of optimum management and maximum place and time utility of tangible and intangible resources at their disposal. Last but not least, the paper discusses the forms of human-machine cooperation, distinguishing three basic types.

Keywords: logistics process, automation of manufacturing, robotization, cobotization, Smart Factories, Industry 4.0, Internet of Things, Cloud Computing

JEL: M11, M21, O31, O33

Introduction

Increased demand for logistics services resulting from increased global demand for goods and services, in particular goods purchased via the internet, combined with a decrease in easily accessible workforce are among the main reasons for the necessity of improving the efficiency and quality of logistics services. Owing to the advancement of modern technologies, the world is developing at a considerably faster pace. Economic entities, faced with the contemporary realities, are forced to search for more efficient, effective and profitable methods of resources management.

As the trade volume grew, and hence manufacturing, so did demand for logistics services in the field of manufacturing and those related to the management of the warehouse, internal and external transport, as well as those aimed at streamlining the management of IT resources. The ongoing fourth technological revolution is one of the phenomena that appeared in response to the conditions of operation of enterprises providing logistics services. This revolution consists in universal digitisation, which is to lead to the subsequent automation of business processes, and thus logistics processes. Digitisation and process automation are carried out through the implementation of advanced IT systems, the use of the Internet of Things, Big Data analysis, i.e. Cloud Computing, and robotization of manufacturing, up to the use of early forms of artificial intelligence.

Going along with the current of the next industrial revolution, enterprises are modernising the existing manufacturing centres or building new automated centres called Smart Factories, where production is optimized through the Internet of Things, Cloud Computing, automation, robotization and cobotization. Thus individual components of manufacturing processes are combined into bigger processing units. The manufacturing space is utilised as a system of reactive modules, where all processes are supported by IT systems which plan, execute and control the ongoing manufacturing processes and the accompanying supporting processes. Speaking of the automation of logistics processes, it is necessary to stress the significant role of robotization of certain tasks fulfilled in these processes, where cobots – robots cooperating with humans – provide significant support for the manufacturing, warehouse and transport staff.

The objective of the paper is to identify the key phenomena and technological solutions affecting the automation processes of logistics processes. The author has identified the technologies that can support human work or completely replace human participation in production processes. Automation processes have been defined as consistent with the assumptions and direction of development of the fourth industrial revolution. The author has pointed to the Intelligent Factory as one of the basic pillars of the fourth industrial revolution. The Intelligent Factory is also the place of implementation and application of technologies previously identified by the author.

1. Method and theory

One of the principal research questions of the paper is to determine how the advancement of the fourth industrial revolution may affect the formation of the system of logistics services to manufacturing enterprises. A major part of the paper is devoted to an analysis and synthesis of phenomena and solutions identified in the contemporary manufacturing industry. Hence the main research method used is an analysis and synthesis of content found in secondary sources, such as books, scientific articles, trade journals and documentation.

Behind each purposeful human activity there is a desire to satisfy a specific need. Needs are commonly satisfied by purchasing adequate products or services. A transaction of purchase by a consumer must be preceded by a properly structured manufacturing process. The manufacturing process is thus identified as an element essential to the satisfaction of needs. Being essential, it must be given the status of a core process. A core process, like the consumer's need from which it originates, needs to be appropriately handled. The handling is carried out through supporting processes, which take the form of logistics processes. The main task of logistics processes is optimum management of the available resources. Supporting processes are therefore intended to give the resources an adequate level of place and time utility. In summary, it is possible to put forward a thesis that every activity leading to the achievement of a goal is accompanied by integrated core processes and supporting logistics processes (Chaberek, 2002). The relationships between the core process and the logistics process are shown in Figure 1.

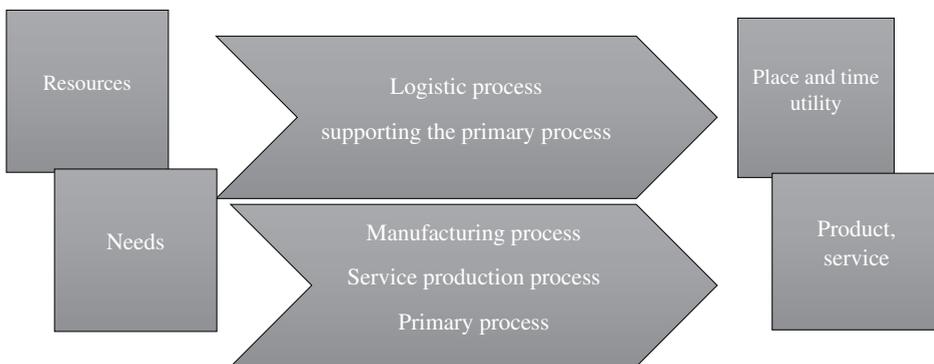


Figure 1. Coexistence of core processes and logistics processes supporting them

Source: (own elaboration based on: Chaberek, 2002)

When identifying the objectives of logistics processes, one cannot concentrate solely on the type of resource which is being moved. The point of logistics activities is largely controlling the processes of flows of resources: raw materials, half-finished products, materials, spares, employees and the accompanying information, in such a way as to offer the customer the highest possible level of service at the specific, lowest possible, cost (Chaberek, 2002).

2. Origin of process automation

The advent of the 20th century marked the decline of the “steam” industrial revolution 1.0, which had continued since the late 1700s (Chojnacki, 2018). Revolution 2.0 meant the invention and popularisation of electricity and the appearance of the combustion engine (Michalski, 2017), which offered possibilities of improving logistics owing to the construction and application of devices already operating in the logistics reality. One of the most noteworthy inventions was the electrical forklift truck, which can be regarded as a milestone in the development of an efficient internal transport system. The first half of the 20th century was a time of building vast industrial plants and regions. One of the basic pillars of industrial revolution 3.0 was the pursuit of optimization by minimising the use of resources while maintaining or even improving the quality of products (Chojnacki, 2018). The third industrial revolution is also a period when enterprises began the computerisation of their activities. The increase in efficiency and the simultaneously falling prices of computer equipment stimulated the implementation of the systems of production control and planning and warehouse management. Thanks to greater precision in the planning and monitoring of manufacturing processes, manufacturing became more flexible and more precise (Płoszyński, 2018). Industrial revolution 3.0 also brought the first attempts at reducing the area of the emerging technopoles. There were attempts at using smaller spaces to obtain the results obtained from bigger areas. This period was also characterised by the first steps at using technology to replace human work with the work of machines or computer systems. In summary, the two principal achievements of industrial revolution 3.0 were the optimisation of the use of resources and the optimisation of manufacturing space management (Chojnacki, 2018). Additionally, it should be noted that it was during the third industrial revolution that intense development was observed in the area of design, implementation and application of software for controlling the flow of goods, materials and information. Since the 1950s, tools assisting in the management of warehouse inventory started to be developed, both in the material and non-material (informational) aspect. The following years brought further development of these tools and the extension of their functionality onto the domain of material requirements planning (MRP), where the first MRP systems were applied. The end of the millennium was a time marked by even more dynamic development of applications supporting manufacturing processes by scheduling production and sales, and finance management in Manufacturing Resource Planning II (MRP) systems up to advanced management systems of material, financial and information resources flow – MRP III/ ERP (Enterprise Resource Planning). These evolved into the most advanced form: ERP II (Extended ERP), which offers the possibility of coordination and cooperation of suppliers and customers throughout the value chain of product or service creation (Wesołowska, 2013). Figure 2 illustrates the successive industrial revolutions, identifying the most characteristic discoveries and advances for each period.

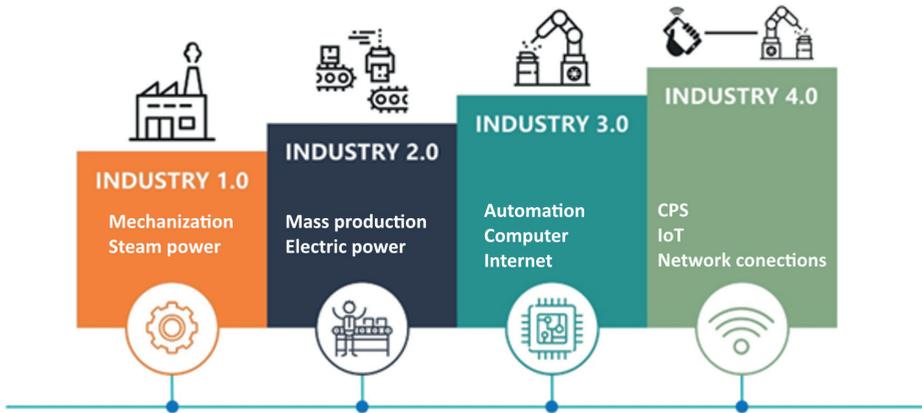


Figure 2. Technological revolutions in industry
 Source: (own elaboration based on: Trillium Network, 2019)

3. Industry 4.0 and its foundations

The ongoing fourth industrial revolution is technologically the most complex one. Dynamic market changes, broad and universal access to modern technologies and innovative scientific research have given new possibilities to the creators of logistics services (Goncerz, 2018a). The high level of education in society, changing lifestyle, migration to cities, strong interest in social media and widespread access to the internet are among the drivers of technological progress. The progress can be defined as a three-dimensional space comprising the following three dimensions:

- smart factories;
- universal digitisation;
- value chain management.

It is therefore obvious that modern enterprises aspiring to market competitiveness should find themselves on all the three planes listed (Goncerz, 2018b). Figure 3 illustrates the components affecting the potential development of enterprises under the concept of Industry 4.0.

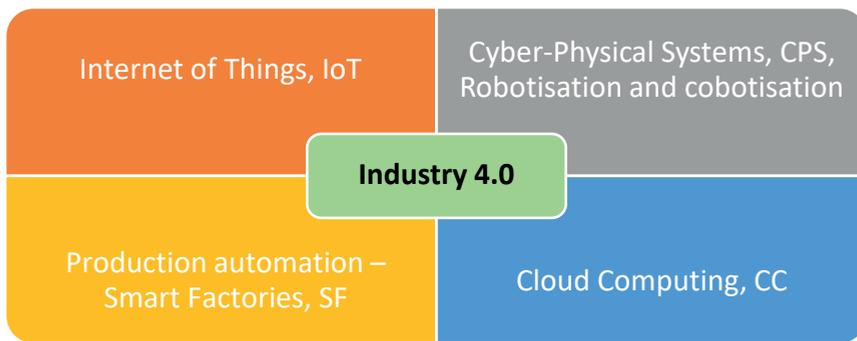


Figure 3. Main components determining the development of the idea of Industry 4.0 as the fourth industrial revolution

Source: (own elaboration)

To face the contemporary market challenges, enterprises need modernisation measures aimed at applying modern technologies, which should lead to partial or even total automation and robotization of manufacturing.

3.1. Internet of Things (IoT)

When writing about Industry 4.0 as a technological trend conducive to the development of automation of logistics processes, it is necessary to recall the pillars supporting the revolution. The first one is the Internet of Things. One of the key elements necessary for continuous development is the appropriate level of data availability (Goncerz, 2018a). The Internet of Things is based on the assumption that all sorts of devices will be connected in a network. This idea somewhat suggests a vision of the future world, where physical and digital devices are connected to an infrastructure that enables the sending, sharing, collecting and processing of information. The concept of the Internet of Things, like any concept, has its main demands: always, everywhere and with everything, which indirectly relate to the time and place utility of transferred and processed data. In order to meet these demands and adopt the concepts of IoT, manufacturing firms have to reach out for a technology that will initially allow them to fully digitalise the processes implemented so that the machinery park and its constituent devices are capable of accurately and efficiently identifying events, communicating and cooperating. IoT is currently considered to be one of the key components of the already omnipresent internet, simultaneously constituting a clear direction of its development and a huge socio-technological leap transforming the perceptions of the methods of resource exploitation (Brachman, 2013).

3.2. Cloud Computing (CC)

Analyses of how many variables and factors, including unpredictable ones, such as climate conditions or disasters, affect production nowadays lead to the conclusion that it is information, its amount and quality that is of a very high value. At the same

time, it needs to be stressed that with the growth rate of the order of magnitude of data growing exponentially, it is not only information itself but the methods of recording, gathering, storing and processing it that prove to be crucial. The next foundation of the fourth industrial revolution is Cloud Computing. The most accurate description of what Cloud Computing is by enumerating the major tasks performed by this tool: performing mass, complex calculations and analyses based on data from numerous feeding channels. Figure 4 presents potential sources of data feeding Cloud Computing. They include, above all, analogue recorders, sensors, transaction records and information “downloaded” from the internet, fora, online shop websites and social media.

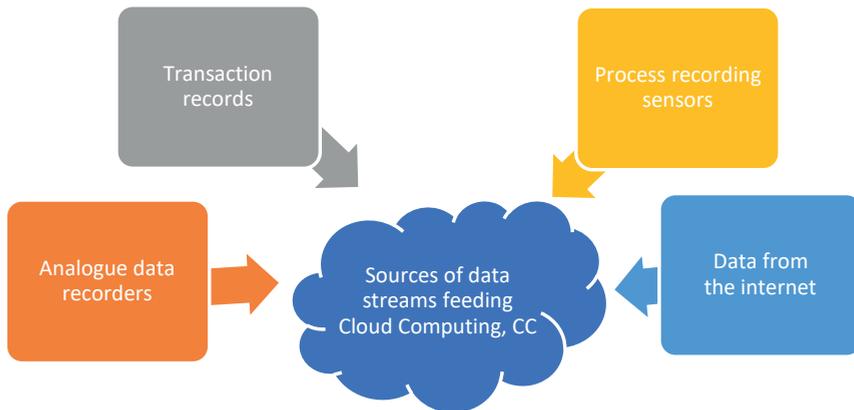


Figure 4. Sources of data streams feeding Cloud Computing
Source: (own elaboration)

Cloud Computing itself is a new kind of service where computing power is a product made available for a payment in the capacity and at the time adjusted to the customer’s needs (Goncerz, 2018a).

3.3. Cyber-Physical Systems (CPS)

Cyber-Physical Systems are an essential element of the fourth industrial revolution. These systems make it possible to build smart networks of communication between people, devices or even products and resources. Growing demand for a highly individualised product requires a lot of flexibility from production lines and systems managing them. As a consequence, the time of potential reaction to external stimuli or those coming from within the enterprise must be as short as possible. The application of an appropriate technology permits efficient and successful human-machine communication. The most commonly used technologies that can facilitate manufacturing processes and communication-related processes in Cyber-Physical Systems are Radio Frequency Identification (RFID), Near Field Communication (NFC), mobile robots and Augmented Reality (AR). RFID is a technology used to streamline the reading of data included in labels or microprocessors

by means of radio waves. NFC is a technology enabling proximity communication between two participants of the process implemented, also based on radio waves. Mobile robots are usually autonomous devices used to transfer resources or goods. Augmented reality is a technology with the strongest impact on human work – through the digital visualisation of elements non-existent in reality, new information or objects are plotted on an element of machinery park, production line or a specific product or resource, existing in reality (Kiraga, 2016).

The current industrial revolution can thus be divided into three clusters: technological, digital and biological. The subject of activity within the physical cluster are all modern materials and technologies. Autonomous devices such as drones, self-driving systems and robots cooperating with people during production-related activities – the so-called cobots – are good examples of such technologies used in logistics processes. The digital cluster is the most essential area serving as the driving force of the fourth industrial revolution. This cluster includes all the devices and solutions enabling access to the internet and the efficient exchange, storage and processing of unlimited amounts of data through it. Hence the universality of digitisation and the great significance of the physical cluster give rise to the refinement of human-machine integration and cooperation. The biological cluster has the least to do with the subject matter of the paper as it involves specialist studies on human DNA codes (Goncerz, 2018c).

4. Robotization in logistics

A high quality of products, one of the key factors of the consumer's decision in today's market, depends very strongly on the quality control system of the manufacturing enterprise. In a modern model factory, the collection of samples, to be later used to evaluate the quality of products, will be performed by autonomous robots. They will be called to the production line by a specialised CPS, which will launch the sample-collecting process on the basis of data transmitted from the production line, sensors built in the production line and a special algorithm (Goncerz, 2018a).

4.1. Automation of logistics processes

Automated production lines, autonomous machines, equipment facilitating warehouse processes and industrial robots, designed in such a way as to minimise the necessity of human work and physical effort, are among the basic elements of the logistics support system. Owing to such systems, less physical power is needed during the picking of products, boxes and containers onto pallets. The concepts of automated warehouse, automatic data management system and automatic distribution of goods in a warehouse are aimed at eliminating human errors in processes associated with the storage of raw materials and goods. The targets of significant automation of manufacturing and warehousing processes also imply a reduction of the physical presence of staff. The reduction of physical participation of people is just one of the elements of savings through automation. No need of physical

human intervention in manufacturing or warehousing processes could also lead to cost reductions in the domain of energy consumption for lighting and heating of the facilities. The implementation of robotization and automation of logistics processes requires all the conducted tasks and activities to be subordinated to a specific management system, usually based on information from CC (Čujan, Marasová, 2018).

4.2. Cobotization in logistics

However, the phenomena of automation and robotization of logistics processes do not lead to absolute elimination of human participation in the process of manufacturing goods or services. Under the concept of Industry 4.0, certain human-machine relations come into being and become consolidated. Technology used in the process of production automation, predominantly in areas related to physical flows and their robotization, can affect employees to a lesser or greater extent. This involves an array of new possibilities, but also numerous challenges. Hence, one of the first steps taken during the automation/robotization of production should be to define the type of interaction between humans, machines and IT systems, coexisting in the production system. Four types of such interaction are generally distinguished: coexistence, cooperation, collaboration and substitution (for human work by machines) (Bauer et al., 2018). Figure 5 illustrates three types of human-machine physical interaction during the performance of manufacturing activities.

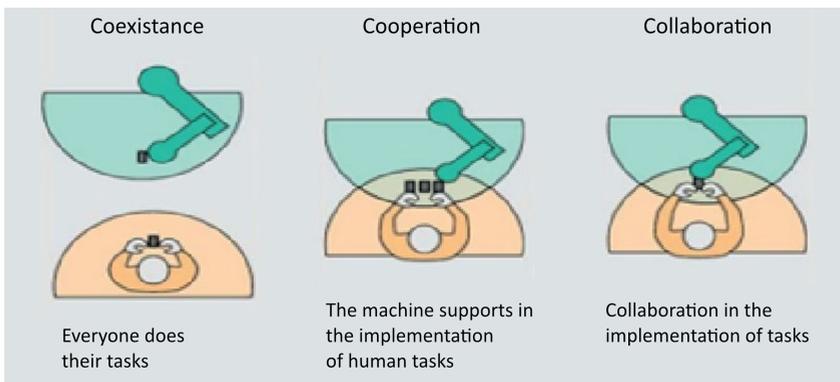


Figure 5. Types of human-machine cooperation

Source: (own elaboration based on: Bauer et al., 2018)

In the case of coexistence, the work areas of the human and the machine are completely separated. Moreover, the machine carries out a completely different phase of the production process, so the goals of the human's and machine's activities are also different. Cooperation shown in the middle image is a situation where the work areas of the machine and the human overlap. Thus, each of them performs certain activities the combination of which is supposed to achieve a common goal. The most integrated form of cooperation is the situation shown on the right of the picture.

Total integration of activity stands not only for a common goal or area of activity, but also jointly performed activities which are complementary. Complementary activities are being adjusted to the current situation, leading to the achievement of maximum productivity of the process implemented (Onnasch et al., 2016).

5.1. Smart Factory (SF)

Technological innovations and their application in production justify a thesis about the next industrial revolution. Intelligent production taking place in factories complying with the generally accepted model of Smart Factory is not only a current trend, but also a response to the demand side of the market and the effect of adjustment to the increasingly common implementation of sustained development policy. However, despite the increasing prevalence of applications of automation and robotization in manufacturing, there is no consistent definition of Smart Factory. A model Smart Factory is presented in Figure 6.

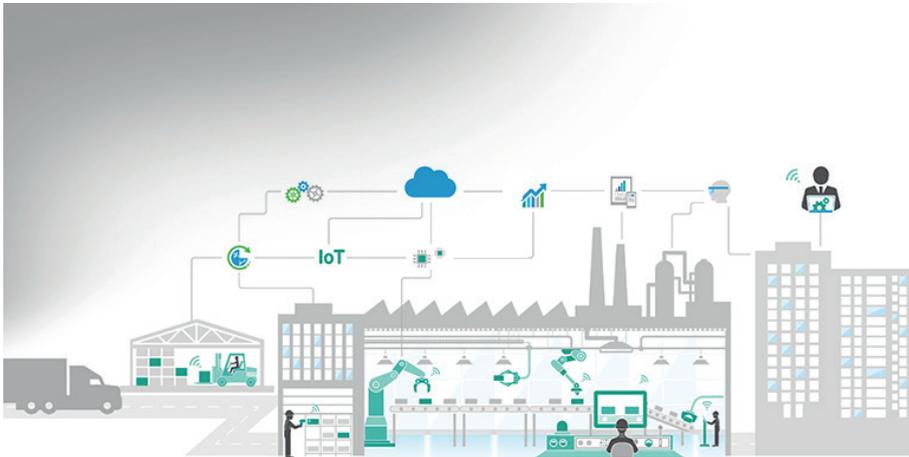


Figure 6. Smart Factory model

Source: (own elaboration based on: Orbis Company, 2019)

A tentative definition of SF should include several characteristics of Smart Factory. Firstly, it is the autonomous and systemic identification of phenomena taking place in manufacturing processes, combined with the ability to record, gather and process data. Secondly, SF uses technologically advanced sensors in the processes of data acquisition and management. Thanks to the sensors, data are processed in real time and oftentimes Cloud Computing is used simultaneously. Also, it is noteworthy that one of the fundamental conditions of the establishment of Smart Factory and its subsequent effective functioning is the use of the Internet of Things. Owing to the previously discussed networking of machines and devices operating in an enterprise, production will involve the cooperation of all the entities participating in the manufacturing process and supporting processes. Such a solution also means that decisions will be made autonomously by using and exchanging

information collected at the appropriate place and time (Cheng et al., 2018). What is important, the functioning of a Smart Factory is not possible without the application of automated production lines, fully or partly autonomous devices and cobots supporting humans at work. Figure 7 presents another major characteristic of SF, i.e. having a constantly updated virtual equivalent of a physical factory whose cyber model is based on digital models.

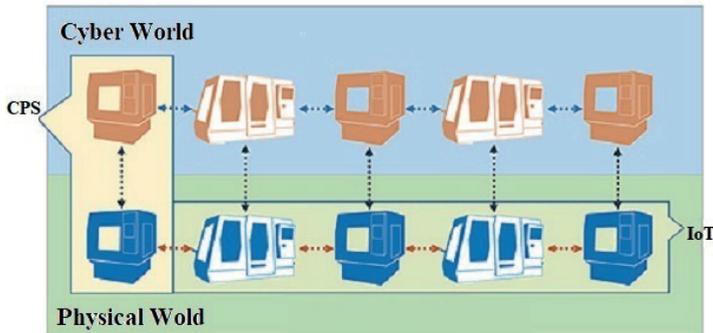


Figure 7. Coexistence of the physical and cyber world in Cyber-Physical Systems
Source: (own elaboration based on: Behrad Bagheri, 2015)

Thanks to this solution, it is possible, on the basis of a virtual factory model, to efficiently and reliably make a synchronous simulation and correction of plans while controlling current production. Giving data an appropriate value and effective utilisation of data offers a lot of potential in terms of reliable decision-making. Through proper integration of the entire production system by means of effective data exchange, a factory can not only improve its flexibility in manufacturing capacity, but also acquire the ability to smoothly adapt to uncertain requirements and conditions imposed by customers or to possible disruptions and failures (Cheng et al., 2018).

6. Discussion

The approach to the automation of logistics processes presented in the paper is different from the way the phenomenon was perceived a few years ago. As the previous third industrial revolution was developing, the idea of process automation was systematised through the use of systems supplied with historical data. Production planning, forecasting and scheduling on the basis of historical data is no longer flexible enough, while the sequence of actions taken during the execution of these functions is too complex. Systems supporting production processes based on the Internet of Things and Cloud Computing, supported by autonomous sensors, have become one of the key methods of adding flexibility to the logistics processes supporting production, warehousing and transport. The study area offers multiple possibilities of a yet deeper analysis of the presented issues and phenomena. Along

with the emergence of innovative technologies, enterprises tend to rush to adjust their machinery park, without adequate planning, implementation, monitoring and subsequent control of the project undertaken. This phenomenon may lead to overcapitalisation or venturing into a modernisation project that the enterprise is unable to finalise or fully benefit from. The source literature is full of overoptimistic descriptions of the automation of logistics processes. In the author's view, however, before undertaking an activity aimed at achieving the expected goal, it is necessary to thoroughly analyse whether a solution leading to full automation always is the optimum solution. A vision of fully autonomous production lines or Smart Factories which are totally independent of employees is real. However, in the author's opinion, the pursuit of this goal should be gradual. Thus a perfect interim phase could be the introduction of partial automation of processes through the implementation of technologies based on human-machine cooperation.

Conclusions

Automation through robotization and cobotization is one of the key methods of streamlining production processes and the supporting logistics processes. The essence of the fourth industrial revolution is best reflected by Smart Factories. Their construction should be composed of elements identical with the identified pillars of Industry 4.0, and so in fulfilling specific goals in production and logistics processes they should be based on the Internet of Things, Cloud Computing and Cyber-Physical Systems. A technology management system thus organised will permit an efficient, effective and beneficial utilisation of the resources at the enterprise's disposal, while complying with the goals of logistics processes, namely giving the tangible and intangible resources adequate time and place utility. Automation does not necessarily mean total exclusion of manufacturing, warehouse or transport employees. Initially, robotization can be introduced by employing cobots to support people at work. Indeed, integral human-machine cooperation can significantly streamline logistics processes while lowering their costs. Robots are able to fulfil certain tasks more efficiently and faultlessly, but very often they are not able to autonomously carry out all the tasks in the entire value chain of a product. Through integral cooperation within Cyber-Physical Systems of humans and machines, enterprises could implement the initial stages of automation of their production processes and build an efficient internal transporting and warehousing system. At the same time, the existence of an information management system, often in the form of Cloud Computing, and the ability of machines to communicate (the Internet of Things) create solid foundations for new Smart Factories or the modernisation of existing facilities, which can become the response to the needs of both the demand and supply side of the market and the solution to the problems tackled by manufacturers and logistics services providers.

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