Industry 4.0: history of emergence, development, prospects of transformation into Industry 5.0

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Abstract. The article is a historical review and characterisation of the period of the fourth industrial revolution. It shows the preconditions for the emergence of Industry 4.0, its place in the development of global industry, its characteristic features, and development prospects. The development of cyber-physical systems, according to experts, will lead to the transformation of Industry 4.0 into Industry 5.0. The characteristics of Industry 5.0 have already taken shape in general terms. Its main features consist in shifting the focus from artificial to human intelligence, searching for their effective interaction, focus on environmental friendliness and customisation of products. Key words: Industry, progress, revolution, cyber-physical systems.

1 Introduction: the concept of Industry 4.0

The term "Industry 4.0" (Industrie 4.0) originated in Germany and was initially used by the German federal government as the name of a strategic plan for the development of German industry, based on the integration of industrial equipment and information systems in a single information space to interact with each other and with the external environment without human intervention. The term was first proposed for wide use in 2011 at an industrial exhibition in Hanover (Germany) in the sense of "a new stage of industrial development, or the fourth industrial revolution". In a number of countries other terminology is used to denote this stage of industrial development: "Industrial Internet" in the USA, "Internet+" in the PRC [1]. The concept of Industry 4.0 is based on digitalisation and automation in various industries, including: the Internet of Things, cyber-physical systems, smart factories, and the Internet of Things.

In scientific literature, the concept of Industry 4.0 is relatively new, there is no unified understanding of the content of this concept in the literature sources, as each author brings its own clarifications. The most complete, in our opinion, definition of the concept of "Industry 4.0" is set out in [2]: "A system of socio-economic relations arising in the process of maximum digitalization and automation of industrial production based on the use of modern cyber-physical, cloud and additive technologies, artificial intelligence capabilities

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and techniques of processing of large volumes of data with the subsequent formation of a global industrial network of business processes, products and services of business processes, products and services". Further in the article we will be guided by this content of the concept of Industry 4.0.

2 Historical overview

Let us consider the place of the period of the industrial revolution Industry 4.0 in the development of world industry as a whole. For this purpose, let us briefly characterise all the periods of the industrial revolution.

The industrial revolution is understood as the restructuring of society under the influence of innovations in engineering and technology. It is impossible to distinguish clear boundaries of each period, as the transition from one period to another is gradual. The first industrial revolution (the great industrial revolution) refers to the XVIII-XIX centuries. It is characterised by the introduction of mechanisation in manufactories, the invention of mechanisms replacing manual labour, the creation of the steam engine and the first loom. The prerequisites for the first industrial revolution were the agrarian revolution in Great Britain in the 16th century, as a result of which the amount of public agricultural land decreased, as a consequence of which a lot of cheap labour appeared in factories, and also the migration of people from the countryside to the cities began.

The second industrial revolution took place in the early 20th century, before the First World War and is associated with numerous discoveries in physics and chemistry [3-8]. It is characterised by the emergence of electricity, the invention of the conveyor belt, the development of metallurgy and automotive industry, the emergence of petrochemical industry, the telegraph, the construction of railways and transport networks.

The third industrial revolution began in the 1960s and is characterised by the development of industrial automation, the invention of the computer, cellular communication, the emergence and development of numerical software control and programmable controllers. The prerequisites for the third industrial revolution are considered to be the use of nuclear energy in industry and, as a consequence, the need to automate nuclear industries harmful to humans. The third industrial revolution led to rapid industrial and economic growth.

The fourth industrial revolution: from 2011 to the present. The emergence and development of the Internet, active development of robotics, additive technologies [9-11], digitalisation of various areas of industry are considered to be prerequisites for the fourth industrial revolution. Many experts, based on the existing dynamics in industry, predict that in the future there will be a shift away from the focus on the mass consumer and reorientation to the needs of a specific person.

It can be concluded that the industrial revolution is a change in the organisation of production and its management strategy associated with the emergence and development of new technologies, raw materials, equipment, etc. Transition to a new level (new period) occurs as a result of an innovative breakthrough in technology, which leads to a chain reaction - transition to a new level in every aspect of the economy and production.

3 Characterisation of the period of the Fourth Industrial Revolution

Let us take a closer look at the characteristic features of the Industry 4.0 period. Unlike Industry 3.0, when the basis of scientific and technological progress was the automation of equipment and technological processes, Industry 4.0 is characterised by large-scale

digitalisation associated with the emergence of big data analysis capabilities, cloud services, smart sensors, the Internet of Things, virtual and augmented reality tools, artificial intelligence and additive technologies. As a consequence, such a concept as "digital economy" has emerged, which implies economic activities based on digital technologies, namely: digital goods and services, e-business, etc. Among the main drivers of scientific and technological progress at this stage is the very high speed of data analysis and transmission. From the point of view of industrial production organisation, it should be noted the increase in the speed of bringing products to market through the transformation of the supply chain into highly adaptive integrated networks, the increase in competitiveness is enhanced by improving product quality rather than reducing costs.

Four principles of the concept of the fourth industrial revolution can be identified: interoperability between man and machine through direct contact via the Internet; the possibility of creating a virtual space that replicates the real world; replacement of human functionality by machine functionality (e.g., working with large amounts of data and performing a number of dangerous tasks for humans); and the ability of systems to make decisions independently and autonomously.

The key technologies of Industry 4.0 are as follows:

— Industrial IoT (Internet of Things) platforms,
— Cloud Computing,
— Additive technologies and reverse engineering,
— Virtual and Augmented Reality Technologies,
— Digital cloning,
— Machine Learning,
— Industrial digital platforms.

Let's take a look at the main systems that form the building blocks of Industry 4.0:

1) Cyber-Physical Systems (CPS). A CPS is a networked system where the meaning of network is implicit in the term CPS. A CPS can be said to include "embedded computers and networks that monitor and control physical processes". At the same time, CPS can be thought of as "a means of supporting the IoT". An integral part of a cyber-physical system are subsystems connected to the Internet. Subsystems, in turn, are part of an open system with a huge number of nodes. Thus, the integration of computational, physical, and natural processes is necessary for a cyber-physical system to function properly. Self-configuring and self-learning systems also play a major role. Let us consider examples of cyber-physical systems: RFID tags; sensors and actuators. Physical and computational systems should be considered in direct interaction, not in isolation from each other.

2) Internet of Things. The Internet of Things is a vast network of computers, sensors (sensors) and actuators (actuators) that are interconnected using the Internet Protocol (IP(InternetProtocol). The main function of the Internet of Things is that it provides a way for "things" and "objects" to interact with other "smart" components to achieve a common goal. The concept of the Internet of Things is based on three basic principles: the communication infrastructure must be widely distributed; each object involved in the interaction must be uniquely identified; each object must be able to send and receive data via the Internet. Perspectives in the development of the Internet of Things include the possibility of big data; remote control of mobile devices; tracking the location of things; and increasing the environmental friendliness of production. An example of the realisation of the concept of the Internet of Things is the smart home.

3) "Smart enterprise ("smart factory" or "factory of the future"). "A smart factory is a manless production facility that uses digital models and artificial intelligence. Such a concept certainly makes it possible to increase competitiveness.

4) Digital platforms. A digital platform refers to a software-based online infrastructure. The functions of digital platforms include information retrieval, data accumulation, and collaboration tools. A digital platform is more designed for coordination than for control. Digital platforms can act as electronic catalogues, marketplaces, intermediaries or service providers, depending on their focus and the user groups they manage to attract. The promise of digital platforms is that they can replace marketplaces and trading platforms.

5) Machine Learning. Machine learning technologies make it possible to "train" computers by means of patterns and logical conclusions. This makes it possible to develop artificial intelligence and expand the range of tasks performed by computers. The principle of machine learning is similar to human learning: to do by example. Thanks to fast analyses of large amounts of data, it is possible to achieve a high speed of performing operations on a computer that would take a person a very large amount of time. The following approaches are commonly used for machine learning: learning with a "teacher", learning without a "teacher", reinforcement learning, deep learning. A training sample with labelled data is used as the "teacher". In "teacherless" learning, the computer has to identify patterns between objects and sort them by itself. In reinforcement learning technology, correct and incorrect decisions are recorded. Deep learning differs from conventional learning in the number of features that the machine must identify for the objects under consideration.

6) Digital Cloning. Digital cloning technologies are based on deep machine learning and can create super-realistic photos, audio and video. The resulting clone (avatar) can be indistinguishable from a real person, which in turn can raise ethical and legal issues. However, among the positive aspects of digital cloning can be the creation of educational materials and historical films.

7) Additive technologies and reverse engineering. The development of additive manufacturing technologies has revolutionised the way we think about manufacturing industrial parts, biomaterials, food, building objects and clothing. 3D printing is no longer something exclusive, available only to industrial companies. Today, anyone can buy a desktop 3D printer and print simple plastic parts for interior design or renovation. A wedding cake can be decorated with figures of newlyweds scanned and printed on a 3D printer from edible materials. No one could dream of this before, but now it is a reality. Perhaps soon mankind will be living in homes printed on 3D printers, as the first experiments of such construction are already being undertaken. Manufacturing industrial products using additive technologies dictates new requirements for the design and geometry of the part. Optimisation of material usage, geometry and bionic design are coming to the fore. Using reverse engineering, it has become possible to create copies of parts and assemblies. This can be applied to repair rare pieces of machinery as well as to modernise existing products. Additive technologies are also actively used for rapid prototyping of objects, which allows for more elaborate and bold designs in various industries and in architecture. The first samples of 3D-printed clothing and shoes have been created. It should be noted that in terms of form, there are significant advances. However, in terms of the materials used, today the technology allows to work only with plastics and metal materials, which is not suitable for comfortable wear by a person in everyday life. Reverse engineering technologies allow to receive scan copies not only of industrial products, but also of premises, large-sized industrial objects and a person. A scanned copy of a person can be used to create a digital avatar. Among the factors restraining the development of additive technologies in Russia is the lack of domestic equipment, materials and software. In the context of import substitution, many young Russian 3D printer companies are just beginning to take their first steps in the market. However, it can be assumed that in the absence of competition with Western manufacturing companies, the development of the Russian additive technology industry will be faster. In recent years, there has been a

significant increase in the share of domestic 3D printer and software manufacturers due to sanctions [12, 13].

8) Cloud computing. This is a technology of network access to computing resources. The advantages of such technology are determined, first of all, by its following characteristics: the ability of the consumer to independently determine the server time, access and processing speeds, the volume of stored data; availability of services for the consumer regardless of the terminal device used; the ability to combine consumers into a single pool and redistribute resources between them if necessary; automatic accounting of resource consumption. All this makes the use of cloud computing convenient and promising.

9) Virtual and Augmented Reality (VR/AR) technologies. Virtual reality refers to the digital world created with the help of a computer. Augmented reality refers to the real world supplemented with digital elements. Both technologies have found widespread use in the creation of architectural design projects, immersive learning, and games. Virtual and augmented reality software is actively developing. Among the disadvantages of the technologies is the dependence on related technological areas, in particular, on the power of the equipment used. Promising areas for the application of virtual and augmented reality technologies include sports, medicine, public security services, marketing. The use of immersive learning allows developing students' creative abilities and increasing their interest in the subject, motivation, and, consequently, the quality of learning [14].

4 Industry 4.0 Development Prospects, Transformation into Industry 5.0

Experts emphasise the following key areas of Industry 4.0 development [2]:

1) vertical and horizontal digitalisation in value chains (vertical digitalisation means digitalisation that takes place within the enterprise and affects all business processes, starting from product ideation and development) vertical digitalisation refers to digitalisation that takes place within an enterprise and affects all business processes, from product or service ideation to after-sales customer service (vertical digitalisation refers to digitalisation that takes place within an enterprise and affects all business processes, from product or service ideation to after-sales customer service; horizontal digitalisation refers to the interaction of factors and actors in the enterprise's microenvironment, namely the real-time integration of all stakeholders along the entire value chain into a single information system).;

2) digitalisation of products (use of smart sensors or communication devices in the enterprise to monitor the status and dynamics of qualitative or quantitative characteristics of products) and services (online training, consultations).

3) digital business models and interactive customer interactions based on data-driven services and integrated platform solutions. Data-driven services and integrated platform solutions;

4) business digitalisation;

5) building a digital culture and teaching digital skills to employees of organisations;

6) ensuring digital trust and optimal selection, analysis and storage of data
data.

The digitalisation of agriculture, the development of "smart factories", and the transition to a knowledge economy can also be considered major trends. Digital agriculture - agriculture based on modern methods of agricultural products and food production using digital technologies (Internet of Things, robotics, artificial intelligence, big data analysis, e-commerce, etc.), which ensure increased labour productivity compared to human labour,

elimination of the human factor, compliance with safety requirements when working with harmful chemicals and reduction of production costs. Of particular interest is the use of robotics in agriculture. Robotisation of agriculture allows, by reducing the human factor, to reduce the cost of production, improve its quality, and increase safety. Robots, unlike humans, can monitor the condition of plants, animals and environment around the clock and correct deviations from the set parameters.

"Smart Factories are also referred to as factories of the future. This term refers to the creation of digital platforms, the complete digitalisation of the product lifecycle, and a system of digital models for both products and production processes. In addition to Smart Factory, there are also such concepts as Digital Factory and Virtual Factory, which are also referred to as factories of the future. Digital Factories focus on paperless manufacturing, Digital Mock-Up (DMU), Smart Digital Twin, digital design and modelling. A virtual factory implies the presence of virtual models of all organisational, technological, logistical and other processes united by an Enterprise Application Systems (EAS) information system.

Knowledge economy is one of the stages of development of innovation economy, where the main values are knowledge and human capital. As a consequence, the development process of such economy is aimed at improving the quality of life, mastering high technologies, innovations and providing high quality services. The transition to a knowledge economy is a prerequisite for the development of the information society. Characteristic features of such a transition are:

1) positioning knowledge as a commodity;
2) positioning knowledge as a productive resource;
3) isolation of the so-called codified knowledge (applied knowledge).

One of the most important conditions for the transition to a knowledge economy is the active development of information and communication technologies and the development of education.

The scientific community is currently discussing the next period of the industrial revolution - the concept of Industry 5.0. The concept is based on the neuro-ecosystem model, which will harmoniously combine the capabilities of Industry 4.0 technologies with the human-centred approach of Industry 5.0 with collective intelligence based on the

combining human and machine intelligence [1]. All experts agree in one opinion: Industry 4.0 and Industry 5.0 cannot be considered separately. The transition from one stage to the other should occur naturally. This transition, according to experts, will be accompanied by the development of cyber-physical systems, which, having emerged during Industry 4.0, will undergo a significant transformation in Industry 5.0. In addition, the very concept of product manufacturing will change: manufacturers will move from mass production to ecological, creative and high quality customized products.

The concept of Industry 5.0 has not yet been specifically articulated. We can only outline its main characteristics: digital twins and virtual reality; BigData-based planning, management and forecasting; blockchain technologies; smart infrastructure; cloud computing; renewable energy; cybersecurity; and biotechnology. The use of digital twins, i.e. digital models of objects, systems, processes and people, will allow us to reach a new level of human development in the future, as such technologies allow us to increase the efficiency of processes and systems [15, 16]. Blockchain technologies are the Internet of the future. Based on the mechanisms of encryption and storage of data distributed over multiple computers connected in a common network, these technologies allow to work with large amounts of information with high speed and high degree of its protection. Renewable energy sources will reduce the negative impact of human activity on the environment and prolong the existence of all mankind [17-39]. Innovative biotechnologies will make it possible to solve the problem of many currently incurable diseases of mankind, prolong the

average age, and bring closer the possibility of human resettlement on other planets. To date, a number of studies in this area are devoted to the cultivation of living tissues on 3D printers, including under weightlessness conditions.

5 Conclusions

As part of the analysis of the characteristics of the period of the fourth industrial revolution, we can conclude that at the very beginning of the period there was an orientation towards machines, which was expressed in a high degree of automation, robotisation, while at present we observe a trend towards human orientation. As a consequence, many experts attribute the future of the Industrial Revolution to "crossing" the machine and the human being, taking the best from each of them. Thus, the Industry 5.0 that awaits us is a time of new discoveries in the development of neuro-digital systems that combine the best features of human and artificial intelligence.

With the development of engineering and technology, the issues of ethics in the use of robotics and neurotechnology and the future of humanity and robots are becoming more and more relevant. It is obvious that we are on the threshold of the transition from Industry 4.0 to Industry 5.0, which is confirmed by the shift of emphasis from automation and digitalisation to the development of human intelligence and product customisation, creation of unique products.

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