MECHANISMS OF DIGITALIZATION OF ECONOMIC PROCESSES OF ENTITIES IN THE METALLURGICAL INDUSTRY: STRATEGIC VECTOR AND PROSPECTS

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Abstract. The formation of digitization of economic processes of metallurgical business entities based on industry 4.0 innovation tools is a powerful strategic vector of the global development of the world economy and is a promising direction of innovative development. *The purpose* of the work is to develop a structural and systemic approach to the formation of mechanisms for digitalization of economic processes of business entities in the metallurgical industry on the basis of industry 4.0 innovative tools: blockchain, artificial intelligence, big data, industrial Internet of things. *Methodology*. The results of the presented scientific research were obtained using general and special methods of cognition (abstract-logical analysis, systematization and combination, method of theoretical generalization, method of dialectical cognition, deduction and induction, statistical analysis. *Results*. A system of factors restraining the development of the mining and metallurgical complex based on the innovative tools of industry 4.0 has been formed. A single system of industry 4.0 digital technologies has been formed. in the mining and metallurgical sector, which includes directions, key innovation tools and digitization trends. To overcome barriers to the formation of a single system of industry 4.0 digital technologies. a scientific and practical approach based on the interaction of the system of adaptation accelerators is proposed and disclosed. The categorical basis for the effective development of the industrial Internet of Things (concept, classification, main subjects) and the directions of the deployed system of IIOT applications have been determined; a scientific and practical approach to the application of IIOT in the system of predictive maintenance of coal equipment of

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the enterprise of the mining sector and in the management system of the maintenance of the transport fleet of the mining company. The effectiveness of the use of artificial intelligence has been proven. In the future, the subjects of entrepreneurial activity in the metallurgical sector are offered the use of Digital Twin technology based on the ISO 23247 standard. A system of competitive principles of blockchain technology has been developed. The conceptual apparatus of Big Data has gained further development: tasks, characteristics of 5 V, structural components. *Practical implications.* It consists in the possibility of using the results of the conducted research for scientific developments and practical activities. The feasibility of systematic use of industry 4.0 innovative tools in the formation of mechanisms for digitalization of economic processes of mining and metallurgical enterprises is proven, which is proposed to be implemented by using a structural and systemic approach, which is built on the principle of hierarchy and provides an opportunity to determine the current vectors of development of mining and metallurgical enterprises. *Value/originality.* The structural and systemic approach, which is built on the principle of hierarchy, is substantiated, which makes it possible to determine relevant vectors and form appropriate mechanisms for the development of mining and metallurgical enterprises based on the innovative tools of industry 4.0: blockchain, artificial intelligence, big data, industrial Internet of things.

1. Introduction

The modern transformational economy poses new challenges to society, the state and business entities, which respond with innovations and revolutionary solutions in all spheres of business. The most important industrial sector is the mining and metallurgical sector, which provides an impetus for the further formation of added value.

Increase of efficiency and productivity, as well as ensuring the health and safety of personnel, are important criteria that can be implemented through the use of new technologies. One of the most influential factors contributing to the socio-economic and human development of the country is the mining sector. The mining industry, providing minerals, plays an integral role in the development of environmentally friendly technologies. Over time, the demand for minerals and metals increases; therefore, intensive mining operations are inevitable for a constant supply of useful minerals.

One of the main catalysts for the development of the mining and metallurgical complex is the industrial revolution and its digitalization tools.

Digital technologies are powerful innovations that can contribute to the improvement of operations, as well as social and environmental sustainability. This phenomenon is amplified in developing countries, the economy of which is focused on metallurgy and heavy engineering. The need to understand the impact, advantages and obstacles of the implementation of digital technologies is crucial for the economy, environment and society of these countries and the entire planet. Consequently, this study provides a detailed overview of the benefits of Industry 4.0 technology in the metallurgy and mining industries and the vectors that can help its wider implementation.

2. System of digital technologies industry 4.0. in the mining and metallurgical sector

Innovative potential focused on continuous development is an important factor in the competitiveness of business entities in the industrial sector operating in a highly dynamic environment. The increase in the variability of the external environment (for example, the shortening of the life cycle of technologies, the shortening of the financial and operational cycle) determines the need for more prompt implementation of open innovations in the activities of metallurgical industrial enterprises. Innovations are the result of innovations (new ideas), they create new product value for the consumer and are used for business development. It can be argued that it is the theory of organization and management, and within its framework, the theory of strategic management that strongly emphasizes the topic of research, development and innovation in the market economy. Research and innovation activity is the basis of the development of enterprises at the micro level and the national economy at the macro level, a vector of competitiveness rates. The metallurgical complex of post-Soviet countries determines the directions of development of national economies. The share of metallurgy in the formation of the GDP of Ukraine is 3-4%, the industrial production of Ukraine is 20%. In the conditions of globalization and integration, the market of metal products is the most important for our country. Ukraine has large reserves of iron and manganese ores, thermal coal, there are active metallurgical enterprises with some elements of modern technologies and still highly qualified personnel, as well as great potential needs for the modernization of the country's existing metal stock. The metallurgical industry is a strategic component of national production, the main budget-forming and export industry of Ukraine's economy [1, p. 8].

In modern conditions of rapid innovative development, new material resources play a significant role: improved alloys of titanium, magnesium, aluminum and copper are used in the military and aerospace spheres, permanent magnetic materials indium, gallium and rare earth elements are necessary for wind turbines, tungsten, titanium, germanium provides acceleration development of high-temperature superconductor technologies, cobalt, manganese and lithium played a decisive role in the construction of electric cars [2, p. 147]. Ferrous metallurgy is characterized by a wide variety of products: steel, cast iron, rolled products, coke, ferroalloys, refractories, pipes. Steel is the main type of product, on which the volume of production of raw materials depends. World steel production has an uneven character with gradual growth. Since 1950, the volume of steel production has increased almost 10 times, 2004 went down in history when producers of ferrous metallurgy exceeded the mark of 1,000 million tons. More than 2% of the world's production potential is attributed to Ukrainian steel companies. Therefore, increasing labor productivity, increasing production capacity, shortening the operational cycle based on industry 4.0 digital tools is an important issue for subjects of the metallurgical industry in today's conditions. The mode of production and work in the field of non-ferrous and ferrous metallurgy has characteristic features: raw materials often change, production processes include physical and chemical reactions, and the mechanisms involved are complex; the production process is continuous and cannot be stopped, problems in part of the process will inevitably affect the quality of the final products. The composition of raw materials, the state of equipment, process parameters, product quality of some industries cannot be measured in time or comprehensively measured. The above-mentioned characteristics of the metallurgical sector are manifested in the difficulties of measurement, modeling, control and optimization, and decision-making. It is possible to overcome the mentioned difficulties in the operational activities of industrial enterprises due to the tools of digital technologies (Industry 4.0).

The lack of natural resources and the increase in the cost of energy have created various problems for the development of the manufacturing industry, specifically the steel industry. As a major part of the production process, energy plays an important role in energy-intensive manufacturing industries (chemical, steel industries) that use large and energy-intensive equipment throughout production and therefore have higher consumption levels than any other sector [3]. Among the energy-intensive and material-intensive industries, smart manufacturing has become the main direction of the industrial revolution and industrial development, in addition, sustainable development has become the consensus of human existence. The manufacturing industry makes a significant contribution to solving environmental problems, and the new round of the industrial revolution forms a modern vector of deep and long-term changes in the work and life of production personnel of industrial enterprises and end consumers.

It should be noted that the containment of the digital vector is carried out not only by internal factors (material-intensive and energy-intensive production), but also by many global factors, such as: a moderate growth in economic dynamics, a significant number of production capacities on the world market, an underdeveloped pricing process, pressure from the end consumer in relation to quality, growing resource nationalism, increasing trade warriors at all stages of the value chain.

There is no reason to believe that these trends will change in the near future. Rather, they are likely to persist indefinitely, defining the industry's "new normal." Moreover, in all industries, the current value chain structure with existing businesses is being challenged not only by macroeconomic conditions, but also by increasingly rapid and pervasive digitalization.

According to Accenture Research's calculations, the implementation of industry 4.0 directions will provide an opportunity to receive 425 billion dollars. of added value until 2025, in other words, will increase the income of the world metallurgical industry by 4%; will provide a total increase in industry assets by USD 320 billion. (the mining sector by 130 billion, the metallurgical sector by 130 billion), will form a sustainable sustainable development of business entities of the strategic industry and reduce the amount of CO_2 emissions by 610 million tons, the estimated value of which for society is equal to 30 billion dollars; will save 1,000 lives and prevent

44,000 workers in the metallurgical sector from getting injured. But there is one of the most significant negative consequences of digitization – it is a reduction in the number of the workforce by 330,000 people, which is almost 5% of the industry's personnel [4].

The starting point for the formation of the digitalization process in industry in 2011 was The Hanover Fair, which formed a new concept for the long-term development of companies with radical technological changes that will be able to create cyber-physical systems both within companies and in entire supply chains. After the start of the industry 4.0 development process, programs (platforms, projects) at the state level begin to appear one by one. The Industrial Internet Consortium program (2014), developed in the USA, brought together the organizations and technologies necessary to accelerate the growth of the industrial Internet. The industrial platform "Factory of the Future" (La Fabbrica del Futuro, Italy) aims to create important research initiatives to increase the competitiveness of Italian industry, in particular "Made in Italy" products in a global context, the development of new products and the improvement of industrial processes. The Global Value Chain Initiative, which is designed to form an industry-oriented view based on the geographical space in the conditions of globalization changes, is noteworthy, this initiative is disclosed in the project Industrial Value Chain Initiative (Japan, 2014).

At the World Economic Forum, the main directions of industry 4.0 digital technologies in the mining and metallurgical industry were formed [4]:

– the maximum transformation of manual labor or man-machine labor into automatic hardware with digital support (sensors, 3D printers);

– usage of virtual and augmented reality, expansion of employee opportunities due to remote tools and remote operation centers;

– integration of information technologies, production and financial cycles, formation of information security of assets;

– using algorithms and artificial intelligence to process data from sources inside and outside the traditional value chain

The new concept of industry 4.0 is a long-term process of development of companies with radical technological changes that can create cyber-physical systems both within companies and in entire supply chains. The growing capabilities of new industry 4.0 technologies are shown in Figure 1.

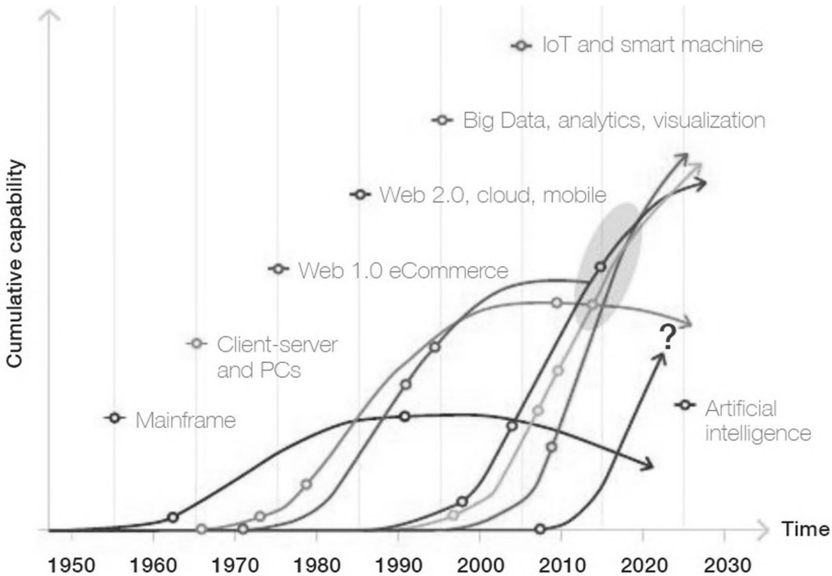

Figure 1. Growing opportunities of new industry 4.0 technologies

Source: [4]

Key innovative tools in terms of the main directions of industry 4.0 in the mining and metallurgical industry are: the Internet of Things, big data, blockchain, cloud computing, human-machine interaction, robotics, open source software, and artificial intelligence.

The mentioned list of innovative solutions made it possible to form a number of technological trends in industrial production: introduction of intelligent sensors in operating lines; artificial intelligence-based development of robotics of industrial lines and technological states; application of "cloud technologies" for computing procedures; formation of a three-level structure of an industrial enterprise (resource planning (ERP), production management system (MES), technological process management system (PCS); use of Big Data technologies in the implementation of the process of industrial analytics; implementation of digitized technical documentation, electronic document flow; sale of industrial goods via the Internet delivery of industrial goods to the final consumer by means of unmanned transport systems.

Based on directions, tools and trends, you can form a single system of industry 4.0 digital technologies in the mining and metallurgical sector, which is shown in Figure 2.

Global mining and metallurgical business entities are spending significant amounts of money to implement digital technologies at all stages of the operational cycle, from procurement to marketing. However, according to the index of digital acceleration, invested funds give twice slower results than in other industries (automotive, chemical). Metallurgical enterprises face barriers to entry to digital technologies, in most cases it is resistance to changes on the part of collectives of industrial subjects who either do not want to master the knowledge base or are afraid of being fired in connection with technological innovations.

In our opinion, it is possible to overcome the established barriers to the implementation of digital technologies with the help of practical adaptation accelerators formed by the Boston Consulting Group [5, p. 6]:

1) Ensuring that the goal of the digitalization strategy matches the capabilities of the industrial enterprise. Executives cite three reasons for this: the lack of customized solutions, the use of traditional cascade models instead of agile methods for deploying digital products, and insufficient

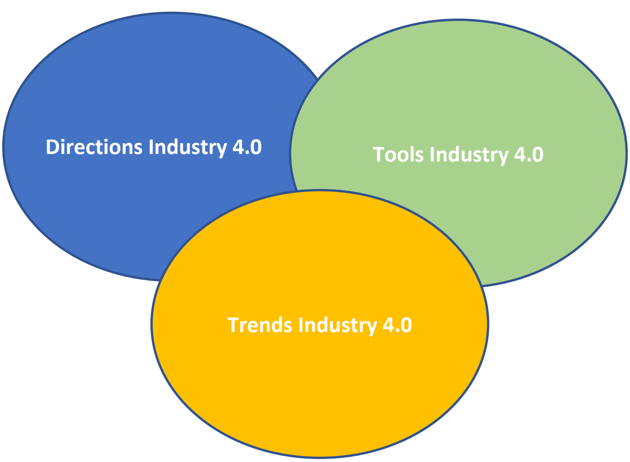

Figure 2. The unified system of industry 4.0 digital technologies in the mining and metallurgical sector

attention to solution sustainability. This issue is solved by an individual approach to operators of digital technology systems, through an intensive course of training in relevant knowledge and skills. In addition, flexible implementation of new information technologies is needed, aimed at eliminating shortcomings and ensuring that developers are fully satisfied with the functions provided. Ultimately, companies must support these digital solutions over time, even as operating modes change, raw material quality changes, and external requirements such as emissions laws change. Some digital leaders have established digital centers of excellence and are upskilling shop floor operators to help develop and maintain solutions over the long term.

2) Intellectual assets are as valuable as existing physical assets in an industrial enterprise. Steel and mining executives argue – often rightly so – that the cost of sensors to collect data is prohibitive, that installation is complex and time-consuming, and that the value of the data is difficult to adequately assess. In this case, you can use inexpensive alternatives, sensor sensors that collect only basic information (temperature, vibration, noise level), and then use artificial intelligence to give them the effect of recognizing the need for maintenance.

3) Combining internal and external ecosystems with the help of digital technologies. For example, combining machine learning at a concentrator and sensor systems at a mine. That is, an industrial enterprise should be considered as a single integrated system that provides synergy from digital technologies.

4) Application of digital tools to all spheres of economic activity. Most industrial metallurgical enterprises lag behind their related industries in terms of digital maturity. It is necessary to implement digital tools not only in the operational cycle, but also to apply them throughout the value chain.

5) Formation of a digital path or road map for the implementation of digital innovations by industrial enterprises of the metallurgical sector.

The use of the ways of implementing digital technologies proposed by the Boston Consulting Group will provide an opportunity to improve the main vectors of economic activity of industrial enterprises: to improve mining productivity by more than 10%, to reduce harmful emissions by 25-30%, to optimize material and technical support.

3. The mechanism of action of the industrial internet of things in the operational system of mining and metallurgical enterprises

The Internet of Things should fundamentally change the way we interact with our environment. The ability to monitor and manage objects in the physical world electronically allows you to transfer decision-making based on data to new areas of human activity – to optimize the productivity of systems and processes, save time for people and businesses, and improve the quality of life. From monitoring machines in a factory to tracking the progress of ships at sea, sensors can help companies get much more out of their physical assets by improving machine performance and extending their lifespan. With IoT devices and wearable monitors, it is possible to improve healthcare outcomes, especially in the treatment of chronic diseases such as diabetes, which currently cause enormous human and economic losses [6, p. 10].

It is predicted that the size of the IoT market will increase from 384.5 billion dollars. in 2021 to 566.4 million dollars. USA in 2027 by an average of 6.7%. This increase is due to various factors: 5G technology for communication; growing demand for data centers due to the growth of cloud platforms; in connection with the increasingly widespread use of wireless networks and sensors and the increase in the IP address space; and advanced security solutions available through IPv6. [7, p. 1546].

According to the analytical agency Statista, over a 10-year period, revenues from the Internet of Things will grow almost 3.5 times, from 181.5 billion dollars to 621.6 billion dollars (Figure 3).

The digitization of machines, vehicles, and other elements of the physical world is a powerful idea. Even at this early stage, the Internet of Things is starting to have a real impact. The Internet of Things is changing how goods are manufactured and distributed, how products are serviced and improved, and how doctors and patients manage health and wellness [6, p. 12].

The Industrial Internet of Things (IIoT) is the next level of Internet of Things (IoT) technology that is unique in its manufacturing transformation. Companies looking for a competitive edge today need only look at the opportunities IIoT can offer, from service, logistics providers, employee workflows and product delivery to enabling manufacturers to digitize virtually every part of their business. Manufacturers can reduce the major

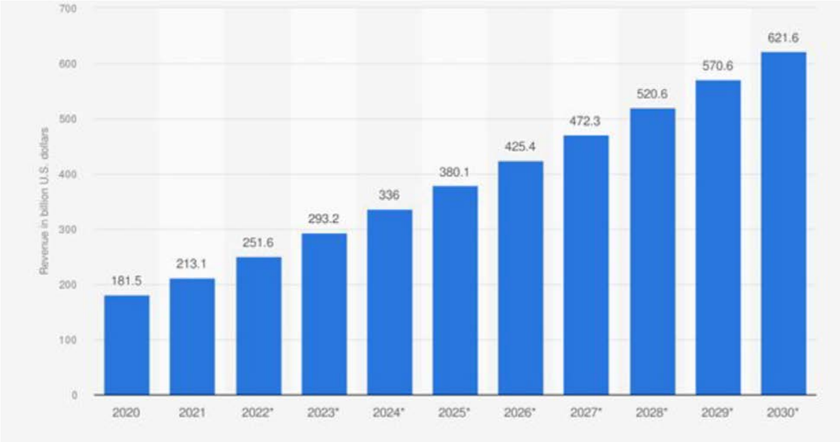

Figure 3. Forecast of revenues from the Internet of Things (2020–2030 period)

Source: [8]

risks associated with manual work and human error by minimizing manual processes and records [9].

The concept of the Internet of Speech was originally derived from the Radio Frequency Identification (RFID) network system by the Center for Automatic Identification, which was established at the Massachusetts Institute of Technology (MIT) in 1999. In this system, all elements can be connected to the Internet using radio frequency identification information, such as sensitive devices. Its main functions included: collection of information; transfer of information; information processing [10, p. 886]. The term "Industrial Internet of Things" is widely used in industrial sectors as digital transformation and connects mission-critical assets, advanced predictive and forward-looking analytics and modern industrial workforce. It is a network of industrial devices linked together by communication technologies to create systems that can monitor, collect, exchange, analyze and provide important new insights. These insights are then used to help industrial organizations make more efficient and faster business decisions [11, p. 15].

The main subjects of the industrial market that make up the industrial Internet of Things market are: IBM Corp., Intel Corp., Schnaider Electric SE, General Electric Company, Emerson Electric, ABB Ltd..Accenture PLC, Tech Mahindra Ltd, Softweb Solution Inc, Sasken. Technologies Ltd., ZIH Corp., Siemens AG. Robert Bosch GmbH and NEC Corp.

According to the forecasts of the analytical agency Statista, the total market volume of the industrial Internet of Things should increase for the period 2020-2028 from 216.1 billion dollars. Up to 1.1 trillion dollars, i.e. almost 5 times (Figure 4).

We have created a classification of the Industrial Internet of Things:

– by type of deployment: hardware; Software;

– by applications: product life cycle management (PLM); production management systems (MES); supervisory control and data collection (SCADA); downtime management system; distribution management system; visualization software; transit management system; remote patient monitoring; farm management system; others;

– by spheres: oil and gas; metallurgy and mining, health care, trade, transport, agriculture;

– by degree of coverage: individual industrial Internet of Things; local industrial internet of things.

The implementation of IIoT is associated with inherent problems for the manufacturing industry, especially for small and medium-sized enterprises in the mining and metallurgical spheres. Most industrial enterprises still operate with outdated machines without data exchange capabilities. This leads to the first problem that manufacturing industry business entities are not ready to receive the benefits of IIoT, such as predictive maintenance [13, p. 102], real-time monitoring [14, p. 475], etc. Most managers and leaders of small and medium-sized industrial enterprises in the metallurgical sector also do not have a deep understanding of IIoT regarding the benefits and challenges associated with it.

The existing literature presents machine modernization in two different categories: "industry 4.0 push" and "need-based pull". In the first category, research is aimed at developing and upgrading all hardware to enable connectivity and data collection for legacy machines, which is a prerequisite for the transition to I 4.0. The second category focuses on specific equipment and improving its efficiency, productivity, predictive maintenance

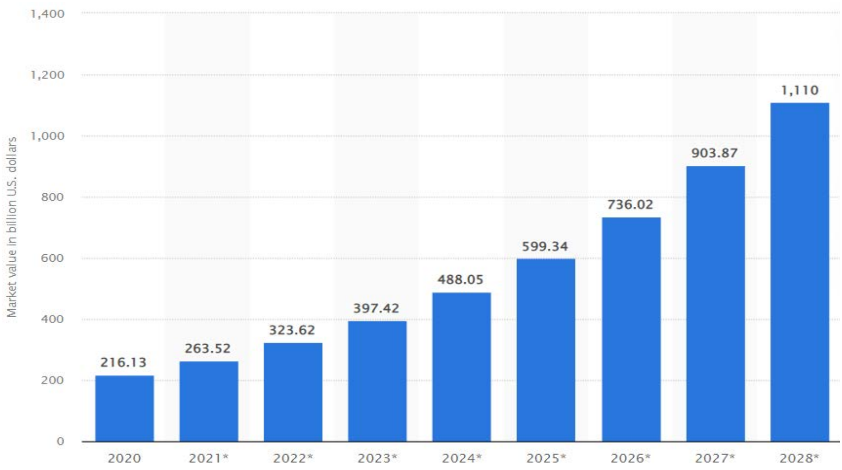

Figure 4. Industrial IoT market size (2020–2028)

Source: [12]

capabilities, etc. That is, we face either an individual industrial Internet of Things or a local one that covers and modernizes all links of an industrial enterprise [15, p. 1050]. However, the core needs in both categories remain the same: external sensors, data connectivity, databases for data storage, data processing, data analysis for predictive maintenance, and security. Scientists Guerreiro and Lins [16, p. 162; 17, p. 12] in their works insist on modernizing the entire industrial enterprise. A group of scientists Fan, Y.C., Chang, J.Y. insist on the point application of the industrial Internet to individual machines and equipment [18]. A more reasonable application of the industrial Internet of Things using cloud technologies is proposed by the group of authors Bosi, F. et al [19, p. 3]. When the focus is on the modernization aspect, one of the main problems is that there is still no universal concept or solution. Moreover, it is likely to be difficult to develop such a concept because the applications vary so much from one company, plant and machine to another that each retrofit is almost a unique solution in nature. IIoT provides valuable information for professionals to improve processes to access data and evaluate it more quickly, autonomously and remotely, as well as to make the necessary changes to the industrial business model. The implementation of Industrial IoT systems provides automatic inventory monitoring, certification of compliance with the plan and warnings in case of deviations. This can allow the control of production lines from the cleaning process to the packaging of finished products. IIoT is a comprehensive real-time process monitoring, recommending operational modifications to improve operational cost management. Розглянемо розгорнуту систему доадтків IIoT: machine monitoring, productivity improvemen, worker safety, improved maintenance, reduction in manufacturing expenses, real-time information, perceive warning, built-in intelligent network, tracking inventory, simplification of the flow of production, it helps machines to discern problems, smart pumping, tracking machines, smart supply chain, monitoring of product development, reduction in expenses, identify environmental variables, automate driving system, reduces mistakes, gain useful information, modify robot action programmes, security, testing of products, continuous improvement, data collections, enhance the quality of product, decision making, remotely controlled, intelligent factories.

All these applications implement the following directions in the operational processes of industrial enterprises:

– increasing productivity and optimizing the use of machines and equipment, using real-time sensors that reflect operating cycle time, the number of production components, idle time, and more;

– optimization of operational efficiency and creation of an effective value chain;

– ensuring the reduction of product defects, the use of digital duplicates when designing products;

– obtaining real-time information about the resources available for monitoring their supply chains;

– reduction of equipment maintenance costs due to equipment monitoring for breakdowns (on the basis of sensors, sensors);

– formation of intelligent networks that combine equipment, machinery, tools and allow monitoring of the entire operational process;

– tracking of an event in the supply chain (this information includes information on the composition, temperature and working environment of raw materials used in the production of the product, other waste, the relevance of transit);

– by integrating data from machine learning and the Industrial Internet of Things, managers can ensure safety for both employees and equipment;

– intelligent tracking devices monitor the degradation of products on the way, which may occur due to the influence of weather, road and other environmental factors;

– the use of unmanned vehicles in the production process, which will ensure the reduction of accidents in the operational process;

– companies can improve existing operations and develop more successful business models by integrating connected systems, devices and sensors into business processes;

– remote control of objects in the existing network infrastructure and the creation of an opportunity for faster integration of the physical world into computer systems, which leads to reduced human intervention, increased efficiency, accuracy and economic benefit.For a visual example, consider the application of Internet of Things technology on the system of predictive maintenance of coal equipment of an enterprise in the mining sector. The system mainly consists of an equipment condition monitoring station, a coal mine monitoring center, and a predictive maintenance and re-repair system. Remote monitoring communicates with the mine monitoring center using a wireless network and does not require the bandwidth of the mine network. The mining monitoring center collects parameter information from the equipment monitoring substation and connects to the remote predictive maintenance center via a wireless network or cable. The remote predictive maintenance center received the monitoring data by contacting the mine monitoring terminal, and the analysis results were sent to the database; Experts and technicians make evaluation and maintenance suggestions through the received parameter values and transmit them to the monitoring terminal in the form of reports over the network [20, p. 886].

A case study conducted by the Altos de Punitaqui mining company at the Fusionada open pit can also be a practical example of the use of the industrial Internet of Things. In many large mines around the world, load and transportation management has been carried out using computer dispatching software since the 1980s. Fleet Management Systems (FMS) have been designed to maximize productivity or reduce equipment requirements to meet production goals, minimize rework, ensure plant supplies, and meet blending goals (when different ore grades are combined to facilitate metal

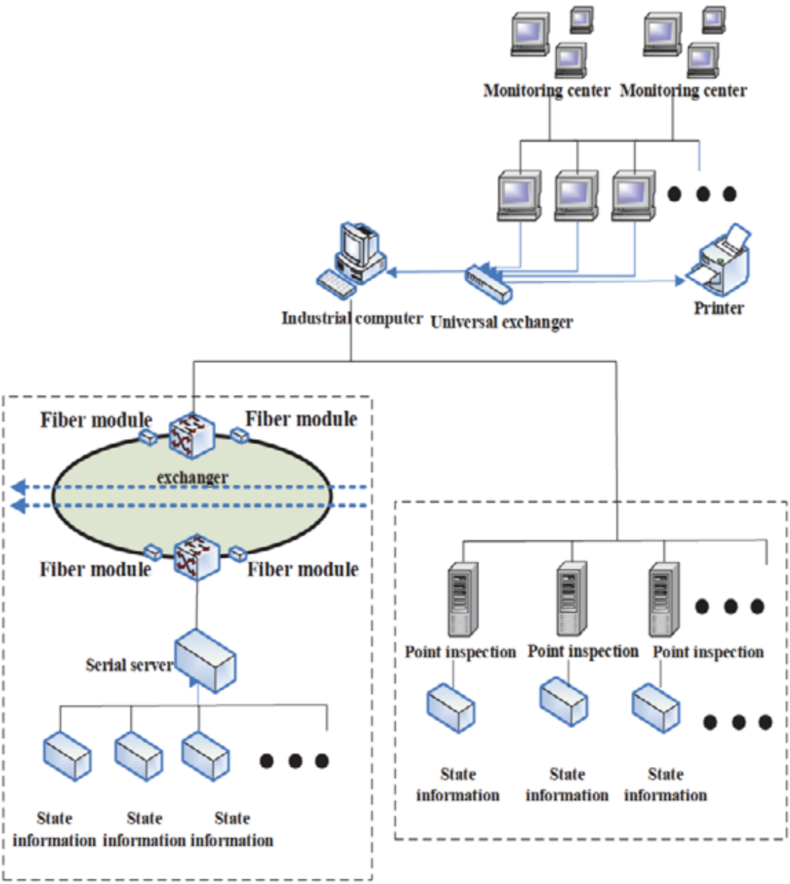

Figure 5. Internet of Things technologies on the system of predictive maintenance of coal equipment

Source: [20, p. 888]

recovery in the mining process). enrichment factories). This research paper presents a low-cost IoT development and implementation of an information system (FIS) instead of (FMS) for medium-sized mines to acquire and process data to optimize loading and transportation processes in an open pit mine in Chile. Thus, the study shows that medium-sized businesses can improve load and transportation management by reporting parameters such as the number of dump truck cycles per day, average load time, dump truck and excavator location, dump truck speed control, and more. These parameters are measured manually or not measured at all. FIS generates some key reports that FMS would provide at a much higher capital and running cost [21].

4. Artificial intelligence and industrial double in the activities of industrial entities

Modern manufacturers have to work in a specific, turbulent environment. Constant social, political and economic changes have contributed to the fact that the previously valid and widely used mass production methods and management strategies adapted to them are no longer applicable. There is a new economy with three main attributes – it is global, it prioritizes intangible resources (ideas, information, connections and knowledge) and it is highly interconnected. These three characteristics constitute a new kind of market and society rooted in a ubiquitous network of connections. The global trend that made the next revolution possible was, first of all, the increase in the amount of available data and computing capabilities. Thanks to them, it was possible to better manage the company's resources, plan production and manage the entire product life cycle. An integral part of global changes and the development of digitalization is the emergence of artificial intelligence as a vector of innovative development of production, products, and simply the formation of the comfort of everyday life in society.

The term "artificial intelligence" is much abused. It has almost become an acronym for any application of advanced technology, obscuring its true definition and purpose. Therefore, it is useful to clearly define AI and its use for industrial companies.

According to PJ. Ågerfalk, the ability to form information gathered from the past and develop possible actions is called artificial intelligence [22, p. 4]. From the point of view of the group of authors Benbya et al. artificial intelligence is the emulation of human-like cognitive tasks using more transparent approaches. One can fully agree with the definition of the group of scientists H. Benbya, S. Pachidi, S.L. Jarvenpaa. The authors claim that artificial intelligence is the ability of a system to identify, interpret, draw conclusions and learn from data to achieve predetermined organizational and social goals [23, p. 285].

Artificial intelligence is defined as a field of informatics that deals with the methods and techniques of symbolic inference by a computer and the symbolic representation of knowledge used in such inference. In the methods of artificial intelligence, data processing is transferred to knowledge processing. The main task of research on artificial intelligence is the construction of machines and computer programs capable of implementing selected functions of the human mind and feelings that are not subject to numerical algorithmization. Artificial intelligence can be succinctly described as "solving tasks as humans do".

The concept is more than sixty years old, since the term was coined in Dortmund in 1956 by McCarthy and his colleagues What was so innovative about McCarthy's idea? Of course, the connection between rational thought and formal logic was established long before that. The attempt to formalize human thought within logical language and, in particular, to provide a concrete method for determining whether arguments were valid dates back to the time of Aristotle and continued into Roman and medieval times. More than three centuries ago, in perhaps the earliest articulation of a logical enterprise, Leibniz conceived a logical language in which to express the basic concepts of human thought and a mechanized procedure for reasoning with those basic concepts. McCarthy pioneered the attempt to formalize common sense reasoning within the formal languages used to represent mathematical truths. McCarthy realized that commonsense reasoning is ubiquitous in intelligent behavior, and therefore a truly intelligent machine must be able to perform commonsense reasoning. He argued that the facts of common sense knowledge could be expressed in formal logic almost as well as the truths of mathematics; and that the process of reasoning with these facts will be very similar to the general methods used to prove theorems in mathematics [24, p. 5].

One of the first attempts to create a "smart machine" was initiated by the Center for Artificial Intelligence at the Stanford Research Institute (SRI International).The Shakey robot was created in the 60s and was the first mobile robot with the ability to analyze its actions and the first system that combined software with AI and physical hardware. Unfortunately, the robot could work normally only in an artificially created test space, and it took more time to fully solve an elementary task. This and other experiments on the creation of intelligent robots did not live up to the expectations of researchers. In 1966, ELIZA was invented by Joseph Weitzenbaum at the Massachusetts Institute of Technology (MIT) Artificial Intelligence Laboratory, which used a pattern-matching and pattern-replacement methodology to simulate the operation of a chatbot. It was the first program to attempt a simulation game proposed by Alan Turing to assess a machine's ability to behave intelligently like humans. Then there were many other chatbots such as PARRY (1972), which was designed to simulate paranoid behavior in schizophrenia, Alice (1995), Cleverbot (1997), Mitsuku (2005) and many others. Domain chatbots and conversational dialogue systems appeared, which were adopted by enterprises to improve customer management. For example, the HMIHY voice dialogue system was used by AT&T to serve callers and direct them to the right place, thereby reducing the cost of engaging human agents for such actions and allowing them to focus on more complex tasks. In 2010, Apple launched Siri, which is the first and most popular virtual assistant. Since then, many companies have launched various virtual assistants such as Amazon's Alexa, Microsoft's Cortana, Samsung's Google Assistant and Bixby, OpenAI's ChatGPT.

Advances in artificial intelligence are rapidly changing the way information is processed in industries such as recruiting, medical diagnostics, marketing, financial consulting and others. Scientists in the field of artificial intelligence have highlighted its following functions: artificial intelligence can imitate complex reasoning and analysis tasks previously performed by human experts, leading to a redefinition of the professional boundaries between human and machine experience; artificial intelligence can speed up the discovery process and the stage of developing new solutions; artificial intelligence can learn from large data sets to develop pattern recognition and make automatic predictions several months in advance compared to traditional analytical tools [25].

As a result of the genesis of artificial intelligence, its main directions were formed: computer vision, natural language processing, speech analytics, decision-making, recommender systems.

Computer vision technologies mean the processing of visual information to extract useful knowledge. This technology is already widely used in robotics, however, its potential has not yet been fully revealed. Computer

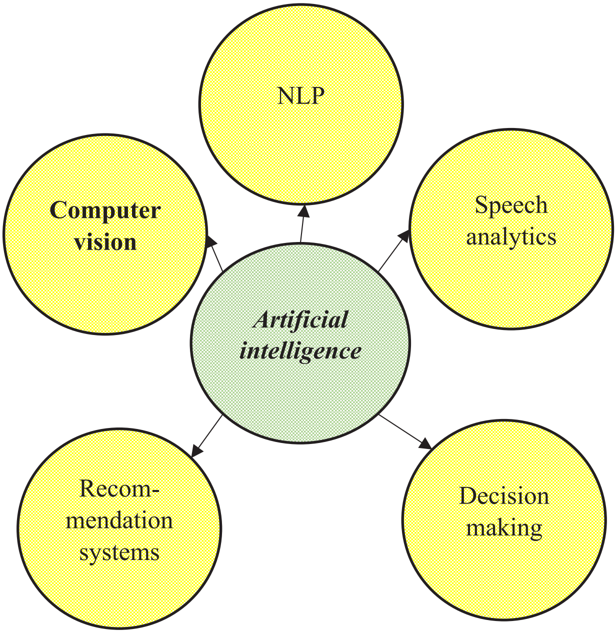

Figure 6. Elements Artificial intelligence

vision includes many tasks: object detection, object tracking, pattern recognition, segmentation, distance depth estimation

As part of the Natural language processing technology, tasks are solved to create artificial intelligence systems that process or "understand" the natural language of human communication. The task of understanding the language is decomposed into extracting essences, morphological marking, and analyzing the emotional coloring of the text. Tasks on recreating the structure and elements of a natural language are also solved – forming answers to questions, searching for synonyms/antonyms, machine translation from one language to another. Chatbots are the most obvious example of the implementation of this technology. The main methods used to solve the listed problems are based on the use of deep recurrent neural networks, as well as their variety of LSTM (long short term memory) neural networks.

Speech analytics is a complementary technology to NLP. If NLP works with text information, then speech analytics works with audio speech, as well as other sounds. The first and, probably, the main task of speech analytics is speech recognition (translating the sound signal of speech into text), as well as determining the tonality of speech – the mood and emotional state of the speaker. Another important task of speech analytics is speech synthesis. The result of high-quality speech almost indistinguishable from human speech has already been achieved – the voice assistants of Google, Yandex, and Amazon have high-quality speech. One of the most popular humanoid robots, Sophia, is also distinguished by high-quality speech. Speech analytics is based on the use of deep convolutional networks, which made it possible to reach a high level of speech recognition and generation. Speech Analytics and NLP technologies are intertwined. It all starts with speech-to-text recognition, then this text is "understood", the necessary actions are performed in accordance with the understood text (by a robot or other device), the corresponding text is generated, which is spoken. Then the cycle repeats. Obviously, this is how maximum similarity with human behavior is achieved, which means that robots' abilities to communicate and socialize increase. In addition, the task of speech analytics includes the biometric identification of a person based on his voice. Service robots will recognize us as soon as we speak (or appear in the field of view).

This decision-making technology / automation of processes (Reasoning) includes the creation of tools by means of which processes are performed without human participation, support is provided in choosing a decision – this wide class of technologies includes tasks for creating expert systems, decision generation systems.

Recommender systems are essentially similar to decision-making technology. However, due to the specifics of such systems – a strong practical component of wide application in service works, we allocate them in a separate class. So, recommendation systems aim to offer the client or user the most interesting objects (goods, services, products, etc.). Each of us has encountered such systems: they can recommend us to read an article, buy this or that product, watch a new series or even a girl (or boy) for a romantic date. Such recommendations are based on collected information about the user. Modern recommender systems are based on the use of both convolutional and recurrent neural networks, in addition, the principles of reinforcement learning are applied.

The metallurgical industry is experiencing an unrelenting trend towards the digitalization of its production processes, which opens up great opportunities in terms of improving process reliability, product quality, socio-economic and environmental sustainability of the entire production chain, although this also involves challenges in terms of staff training and updating monetization procedures and control. Digitization paves the way for increased exploitation of artificial intelligence to fully exploit the information conveyed by the large amount of disparate data collected in steel plants today. All processes of industrial production require balanced, strategically correct project decisions, which is not possible without the symbiosis of artificial intelligence models, machine learning, robots, autonomous agents, and humans themselves.

Many industrial companies face the common problem of determining the most relevant data when solving a specific task. AI can speed up this process by ingesting vast amounts of data and quickly finding information that is most likely to be useful to engineers when solving problems. For example, companies can use AI to reduce cumbersome data verification from half an hour to a few seconds, thereby freeing up 10 to 20 percent of the productivity of highly skilled engineering teams. In addition, AI can also detect relationships in data previously unknown to the engineer. After ten years of information gathering, companies often have a large amount of data, but poor understanding, which makes it almost impossible to search for relevant information among millions of structured and unstructured data records. Engineers often have to rely on their previous experience, talk to other experts and search for the necessary information in piles of data. Companies can teach AI to navigate structured and unstructured technical documents with large amounts of text by providing it with important technical dictionaries, lookup tables, and other information. Then they can create algorithms that help AI understand semantic relationships between different texts.The work of a group of scientists M. Vannucci, V. Colla, M. Chini, D. Gaspardo, B. Palm can serve as a successful example of the application of artificial intelligence in the metallurgical industry. This work was developed in collaboration with the electrometallurgical plant located in the north of Italy and owned by the company Ferriere Nord (FENO).

The proposed artificial intelligence system is dedicated to predicting the state of aging of ladles working on the installation of continuous casting of blanks of an electrometallurgical plant. The problem is faced from the perspective of predictive maintenance. In fact, prompt detection of critical bucket wear avoids process and productivity issues, as well as lost profitability. The paper proposed two models based on Decision Tree (DT) and Random Forest (RF), respectively. The proposed artificial intelligence system can be used either as part of a management decision-making model that tells operators when to start the bucket maintenance cycle, or, in a more automated framework, can be used to schedule bucket operations and plant maintenance operations scheduling [26, p. 334].

As already mentioned above, non-ferrous metallurgy is one of the most important sectors of the mining and metallurgical complex. According to the Stratistics MRC study, in the long term, an increase in world consumption of non-ferrous metals is predicted (growth in copper consumption – 1.7%, aluminum – 1.5%, zinc – 1.7% in 2030) due to: an increase in consumption in traditional sectors (meeting the needs of the growing population and urbanization); increase in consumption in new sectors of the economy (RES, new transport); difficulties of substitution with alternative products (except lead). According to the forecast of the International Copper Study Group, the deficit of copper on the world market was predicted at the level of more than 90,000 tons. The consumption of aluminum for the production of one car will increase on average from the current level of 120 kilograms (kg) to 250 kg in 2025, which will create an additional need for 12-16 million tons of aluminum per hour by 2025, and from 27 million to 35.2 million tons per hour by 2050. The increase in zinc consumption will be provided by the metallurgical industry (galvanizing), the production of brass and bronze. Growth in the production of new types of vehicles will create an additional demand for zinc in the amount of 2.4 million tons per hour by 2030 and 3.6 million tons by 2050. Machine vision is one of the most rapidly developing and popular areas of AI application in non-ferrous metallurgy. The main attention is given to the development of technologies that allow you to receive images of objects in the real world, process and analyze them, and then use the data to solve applied problems.For example, for the control of a specific production site, it allows to quickly track the closure of the cathode and anode in the electrolysis shop, to recognize the material moving along the conveyor, and to classify it by quality [27, p. 4].

Artificial intelligence plays a very important role in the activities of mining companies. Vision artificial intelligence systems allow mines and quarries to collect detailed, accurate and timely data about their operations at the facility level.

Data collected in the artificial intelligence system can be accessed in the form of digital twins or clouds of points representing the deposit in three dimensions. Such data are usually collected by manned or unmanned aerial vehicles equipped with LiDAR technology, or aerial photographs. Depending on how the data is collected, their accuracy can be several centimeters to many square kilometers. Other data in the system of artificial intelligence of machine vision may include these and other elements, for example: accurate estimation of reserves or volume of material loosened by explosive works; exact geometry and condition of access roads; distances between any points of the mine; exact placement of mining equipment; precise protective devices [28].

The development of artificial intelligence (artificial intelligence) determined the development of the new concept of "Digital Twins". A digital twin (Digital Twins) creates a virtual model of a physical object digitally, promotes interaction and integration of the physical world and the information world, and also creates a reliable bridge for industrial information integration [29]. A digital double can simulate various processes that material objects can go through and predict their performance in difficult conditions. In other words, a digital double is a simple algorithm that predicts how a product or process will perform based on real-world data. Digital Twins in most cases include the Internet of Things (IoT), artificial intelligence (AI) and data analytics to improve output and other supporting data (device firmware, configurations, calibrations, settings data).

Developers create digital counterparts or virtual models that can receive feedback from sensors associated with the physical system. Sensors collect mission-critical operational data, and a digital model simulates what is happening in the physical system in real time. Users can use a digital doppelganger to explore options for extending product life, improving manufacturing and processes, building a product, testing a prototype [30, p. 72].

A recent study by Marketsand Markets shows that the global digital doppelganger market size was estimated at USD 3.1 billion in 2020 and is projected to reach USD 48.2 billion by 2026. Global Market Insight estimates that the digital doppelganger market size, estimated at $8 billion in 2022, is expected to grow at a CAGR of approximately 25% from 2023 to 2032.

In today's conditions, design and production mainly use digital doubles to provide an accurate virtual representation of objects and modeling of operational processes: managing supply chains; tracking transactions; in vehicle maintenance; in the process of remote assistance; when visualizing assets and customizing the design [31].

Creating a digital counterpart in Omniverse for architects, engineers, and construction crews to collaboratively evaluate projects can help accelerate design and deliver contracts. Most industrial automation systems support a functional mock-up interface (FMI) to integrate a real-time version of a digital double to run in parallel with a real machine. This allows you to quickly plan work and test in a virtual environment before making any changes to the computer system. The Digital Twins solution is useful for scheduling and operations in the mining industry. Simulation of the working environment allows miners to create long-term and short-term programs. In addition, they can make accurate calculations for drilling, crushing and mining.Moreover, workers in the field can use Digital Twins solutions to simulate equipment, mechanisms and the entire work process, and can test innovations in their most important work processes [32].

Increasing demand for automation in various industries is an expected factor that will create high demand for the Digital Twin platform in the long-term. As the global digitalization process develops, Digital Twin solutions will play an increasingly important role in various industries. To facilitate the implementation of digital twins in production, ISO recently developed the standard ISO 23247 – Digital Twins Platform for Manufacturing [33, p. 27]. The standard provides a common development framework that includes subsystems and components that manufacturers can choose for their own digital twin implementations on a case-by-case basis. It helps industrial operators to systematically identify the applicable components, their parts and the characteristics of their interactions. The ISO 23247 standard series currently includes four parts: overview and general principles, reference architecture, digital representation and information exchange.

5. Development of business flows of metallurgical enterprises based on block chain technology and BigData

In recent years, blockchain has attracted considerable attention from researchers. This is a kind of decentralized distributed database that originated from Bitcoin. It is distinguished by a combined but creative use of existing computer science methods, such as a distributed data store, a peer-to-peer network, a consensus mechanism, and an encryption algorithm. Blockchain is based on a consensus mechanism that allows everyone to agree on a newly created block of data and work together to maintain all blocks in the form of a unique database [34].

Blockchain technology can fundamentally change the way the mining industry and related supply chains work. Blockchain is an immutable and cryptographically secure archive of records stored in a distributed ledger that uses smart contracts created on the Ethereum platform. This technology allows interested parties connected to the chain to securely exchange important trade documents, such as bills of lading and letters of credit, using smart contracts. The advantages of blockchain technology are ideally connected to the commercial and operational aspects of mining, metallurgy and other industries [35]. In other words, digital mining is digitized, technologically mediated production, storage, analysis and distribution of data obtained by tracking and tracing the physical origin and socio-ecological impact of minerals and other natural resources. First of all, blockchain technology entered the lexicon of the mining industry with the promise of from the need for intermediaries or trusted partners to verify, audit or certify information about the supply chain. Being an improved version of distributed ledger technologies, blockchains effectively expand the scale and socio-economic impact of existing tracking initiatives. Government and corporate entities have begun to promote and certify more transparent and ethical mining methods to reduce environmental and reputational risks associated with exploration and mining methods, from corporate social responsibility programs to the emergence of new regulatory standards for mineral supply chains [36].

Blockchain can also be used for complex end-to-end tracking of ores and minerals. The process requires that sealed bags or containers with concentrates and ore be stamped with a unique identification number, which will subsequently be registered in the blockchain. The identifier will contain information about the quality and quantity of each batch of ore or concentrate, and will also be constantly updated with constant tracking of the time scale and registration of movements [35].

If we consider steel enterprises, then in August 2019, Metinvest concluded a contract for the supply of equipment through the we.trade blockchain platform. In May 2020, mining giant VNR completed a blockchain iron ore deal in China. In July 2020, Nanjing Iron & Steel closed a blockchain deal to buy iron ore in Australia.

In our opinion, it is necessary to form a system of competitive principles of blockchain technology:

– the principle of a secure system of contracts (smart contracts). The subject of the metallurgical sector automatically receives cash upon delivery of the goods to the consumer's destination;

– the principle of a transparent supply system. Transparency consists in the ability to trace the origin of goods at each stage of promotion to the final consumer;

– the principle of document authentication. A good example is the SAP project to create a single industry certificate registry based on the blockchain for metal products. The purpose of this register is to verify the authenticity of certificates and, thus, fight against counterfeit products, which, according to expert estimates, exceed 10% of the total volume of consumption;

– the principle of digital analogues of real assets (tokens). These are new financial instruments on the stock market [37].

In the era of big data, a huge amount of big data generated by the processing industry has the characteristics of ultra-high dimensionality. How to work with this ultra-high-dimensional data, exploit its potential value, and develop a data flow model suitable for the new production environment is a complex problem. Currently, analysis based on big data will bring more ideal advantages to the production sector thanks to the mutual support of relevant new technologies against the background of Industry 4.0. The process of data analysis is aimed at increasing the transparency of decision-making [38].

Big Data is unstructured data that differs not only in volume, but also requires special approaches to storage and processing. Unlike traditional databases, where information is stored in accordance with the internal structure and algorithms of the application, disparate objects – documents, media files, e-mail elements, folders with files – are difficult to consolidate, organize centralized management and provide search, since the data is unstructured.

Big Data defines three main types of tasks: storage and management of data volume in hundreds of terabytes or petabytes, which ordinary relational databases do not allow to use effectively; organization of unstructured information consisting of texts, images, video and other types of data; analysis of big data, which raises the question of how to work with unstructured information, the generation of analytical reports, as well as the introduction of predictive models.

The characteristics of big data can be summarized and determined using 5 V: high capacity (large volume of data), high speed (data is generated and updated at high speed). speed), great variety (data generated by various sources appear in different forms), high accuracy and high value (huge potential value hidden in the data) [38].

Data sources in production are usually divided into the following aspects:

1) Data on production resources: data on the productivity of intellectual devices in real time, collected using the technology of the Industrial Internet of Things, production data in its service system;

2) Production systems and computer data include product design, order configuration, material distribution, production planning, business management, etc.

3) Internet data: open websites, such as websites of state social services, e-commerce platforms (Wal-Mart, Amazon, etc.), social networking platforms (YouTube, Facebook, Twitter, etc.).

Since every stage of a mining company's value chain produces large amounts of data every day, big data plays a critical role in improving business intelligence and predictive analytics decision-making processes. However, to achieve this goal, mining companies need to determine how to manage the diverse data available, what data to collect, and how to prioritize.

Mining Global looks at five ways to use big data:

1) Access to data to improve business operations. Big data can contribute to faster and faster adoption of business solutions based on business analytics and predictive analytics.

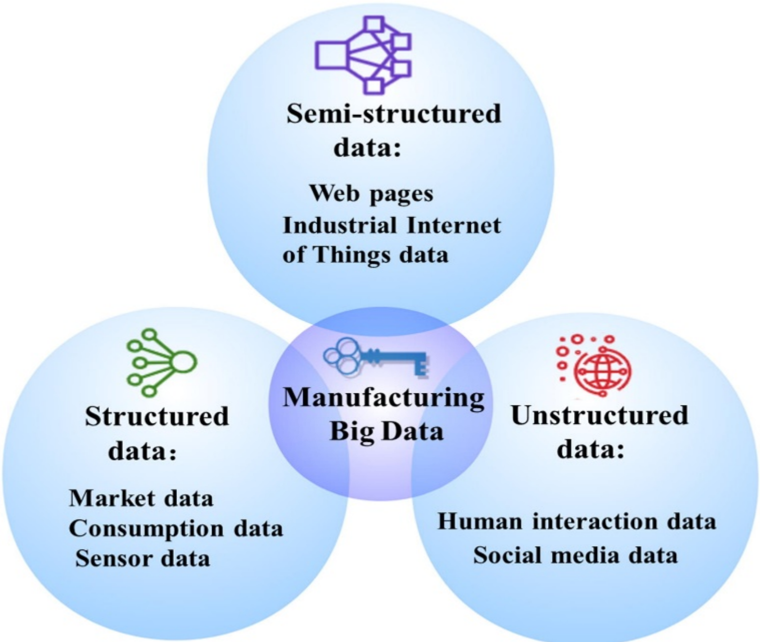

Figure 7. Sources of industrial big data

Source: [38]

2). Reduction of downtime and improvement of equipment efficiency. Such data as tire pressure, scheduled repairs, malfunctions and information about the driver (routes in place, speed, correct use) can be collected, analyzed and reacted.

3) Personnel management and operational efficiency. Big data can help facility managers gather more accurate and detailed performance information across everything from inventory to sick leave, thereby identifying variability and improving productivity.

4) Big data and constant improvement. Big data can be used not only to manage current operations, but also to improve operations in the future. Mine managers can get an idea of the most productive working days and study the conditions surrounding them. These conditions can then be replicated to increase productivity and efficiency in the future.

5) Risk minimization. Sophisticated analytics can significantly improve the decision-making process, minimize risks, and reveal valuable information that would otherwise remain hidden [39].

6. Conclusion

As a result of powerful impulses of innovative changes, a new wave of the industrial revolution industry 4.0 was formed. The metallurgical and mining industry, as the foundation of added value, is being transformed like no other due to the digital tools of the industrial revolution. As a result of the research, a system of factors restraining this development was formed: material-intensive and energy-intensive production, moderate growth of economic dynamics, a significant number of production capacities, an underdeveloped pricing process, quality pressure from the end consumer, growing resource nationalism, increasing trade wars. A single system of industry 4.0 digital technologies has been formed. in the mining and metallurgical sector, which includes directions, key innovative tools and trends of digitalization, which will provide an opportunity to obtain an economic effect in the form of 425 billion dollars. added value and total increase of industry assets by 320 billion dollars, as well as the social effect of reducing the amount of CO_2 emissions by 610 million tons. and 1,000 people who will remain alive. To overcome barriers to the formation of a single system of industry 4.0 digital technologies. proposed and revealed a scientific and practical approach based on the interaction of the system of adaptation accelerators, such as: the affinity of the goal and possibilities of the digitalization strategy, the unified value of digital and physical assets; combination of internal and external ecosystems with the help of digital technologies; formation of a digital path (road map) of the metallurgical sector. In the future, we defined the categorical basis for the effective development of the industrial Internet of Things (concept, classification, main subjects) and the directions of the deployed system of IIOT applications; a scientific and practical approach to the application of IIOT in the system of predictive maintenance of coal equipment of a company in the mining sector and in the management system of maintenance of the fleet of transport by the mining company Altos de Punitaqui at the Fuzhnada open pit. The genesis of the development of artificial intelligence and its main directions are substantiated: computer vision, natural language processing, speech analytics, decision making, recommender systems. The effectiveness of the application of artificial intelligence has been proven on the example of the company Ferriere Nord (FENO) and directly on its electrosmelting plant. In the future, the subjects of entrepreneurial activity in the metallurgical sector were offered the use of Digital Twin technology based on the ISO 23247 standard. A system of competitive principles of blockchain technology was developed: the principle of a secure system of contracts (smart contracts); the principle of a transparent supply system; principle of document authentication; the principle of digital analogues of real assets (tokens). The conceptual apparatus of Big Data has gained further development: tasks, characteristics of 5 V, structural components.

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