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The usege of artificial intelligence in the activities of mining enterprises

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Abstract. The achievements of Industry 4.0 are penetrating more and more widely and deeply into various spheres of economic activity. The article discusses the directions of using artificial intelligence (AI) in solving the problems of development in mining enterprises. Methods of achieving results in various directions using AI have been determined. Based on the characteristics of neural networks formation components, the model of the integration of neural networks into the information system of the mining enterprise as well as the main components of this model, their connection and dependencies are determined. The architecture of the proposed information system is described, which consists of four zones: the corporate zone, the operational zone, the control zone, and the intermediate zone. It was hightnlined that the functioning of the operating system of this model depends on the sensors that are installed on the mining equipments in the operational area of the enterprise. It is noted that the number of such sensors depends on the amount of data accumulated because of the activity of the enterprise's equipment and the efficiency of the construction and functioning of neural networks. The factors that determine the effectiveness of the model and the precision of neural networks in the activity of mining enterprises are substantiated. It was established that the main criterion is the amount of information needed to analyze the object's behavior and the possibility of predicting it in the future. The dependence of the effectiveness of the application of AI technologies on the level of digitization of the enterprise was considered, and it also proposed to determine the indicators of the accuracy and efficiency of the functioning of neural networks in the information systems of the enterprise.

1 Introduction

Minerals play an important role in a country's development, accelerating economic growth, ensuring energy security, and contributing to social and technological progress. Minerals are the source of a significant part of the country's economic income through their extraction, processing, and export. In Ukraine, during the last decade, the extractive industry accounted for 12 – 16% of the volume of industrial production of Ukraine, and in the total GDP of the country was about 6%. In recent years, the volumes of production of

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the main types of minerals have remained relatively stable (changes – up to 10%), apart from coal production (the reduction since 2014 is due to the loss of about 57% of the mining fund in the territories of the temporarily occupied Donetsk and Luhansk regions). According to the rating of the World Mining Congress 2023, Ukraine ranks 24th in the world among mining countries, the volume of mineral extraction in the country is estimated at 107.7 tons (about 20.17 billion USD in value terms) [1].

Abundant mineral deposits allow the country to ensure energy security, achieve energy needs and reducing dependence on imports. Mining can stimulate the development of infrastructure such as roads, railways, and ports, which contribute to economic growth and improved living standards. The industrial sector related to the extraction and processing of minerals creates a significant number of jobs and contributes to employment. The development of technologies related to the extraction and processing of minerals leeds to technological progress in the country, which can increase its competitiveness in the international market [2 – 4].

The fourth industrial revolution created the prerequisites for the full realization of the potential of minerals at a much higher quality level [5]. Artificial intelligence (AI) plays an important role in this. AI can be used to optimize various aspects of mining operations, including development planning, transportation routing, supply chain management, and more. Machine learning algorithms can analyze large amounts of data and identify optimal solutions, resulting in increased productivity and reduced costs. AI helps identify potential risks in mining operations and predict their consequences, allowing businesses to develop effective risk management strategies and ensure the safety of workers and equipment. Artificial intelligence systems can analyze information coming from sensors and monitor the state of equipment in real time. They detect deviations in the operation of machines and predict potential breakdowns, allowing breakdowns to be carried out before serious problems arise. AI helps implement automated and robotic solutions in mining. Jobs with dangerous, repetitive, or labor-intensive operations can be outsourced to robots, reducing risks to workers, and increasing productivity. AI helps improve the energy efficiency of mining equipment and continuous processes. It analyzes data on energy consumption and determines optimal strategies to reduce costs and emissions CO_2. AI can be used to optimize the planning of mining resources and logistics. She develops optimal routes for transporting resources and coordinates the work of all departments and warehouses. As a result, the application of AI helps enterprises in the mining industry to increase efficiency, reduce costs and ensure safety and stability of production.

The work of scientists is devoted to the study of the prerequisites for the introduction of AI in the activities of enterprises. The development of digital technologies as an important background for change is explored in the source [6]. Modern trends in the development of energy, which require the use of digital technologies, are considered in the source [7]. The prospects of using AI through gamification are considered [8]. The study of the readiness of enterprises operating in the field of energy resource extraction is studied in the source [9]. Studies of cognitive abilities through training and obtaining additional knowledge were studied in the article [9].

Acquaintance with literary sources made it possible to identify ways of applying artificial intelligence in the activities of mining enterprises. The practical application of machine learning technologies in the dispatching system at a mining enterprise to increase the efficiency of operational management of the enterprise, increase reliability and maneuverability, record and monitor the operation of the mining and transport complex is presented in the source [11].

The source [12] describes advanced research in the field of machine learning and considers the possibilities of structuring and processing important data by company employees without the need for deep programming knowledge. The creation of special applications allows employees of mining enterprises, despite the lack of coding skills, to face the challenge of fully adopting these techniques for solving real tasks to perform data analytics and apply machine learning to any structured data. The paper [13] reviews the application of deep learning in the mining and processing of ores, noting that deep learning is strongly impacting the development of sensor systems, particularly computer vision systems used in mining and mineral production.

Source [14] describes the use of AI for the study of mineral resource production flows to update data on the current state of mineral resources. Authors of the article propose an ore grade prediction method using an artificial neural network (ANN) [15]. Worthy of attention in accordance with the purpose of this article is the publication [16], which is considered as a platform for the integration of new enabling technologies and systems with the use of AI in the activities of mining enterprises. The results of studies on importance of sensors in the use of AI deserve attention. Sensors play a crucial role in factory automation in making the system intellectual. Different types of sensors and methods of their application are investigated in the source [17].

2 The choice of object to study

Let's consider the tools that today form the basis of AI. Performance data forms the basis of data analytics, which provides information sufficient for informed decision-making. Analyzing the collected data allows the creation of algorithms to improve the decision-making process by generating insights about events, actions, or situations. The cognitive component of AI, which includes a human-like level of interaction between humans, allows the collection of basic data and technologies that shape AI machine learning algorithms that improve over time with more data. Deep learning as a subset of machine learning that uses neural networks allows working with huge amounts of data for learning to make decisions for a variety of situations that may arise in everyday life.

Hence, AI's ability to process and analyze huge amounts of data in a short amount of time opens new opportunities for the mining sector, which has traditionally relied on more manual and labor-intensive methods of operation. Let's consider the areas of use of artificial intelligence in the activities of mining enterprises.

Research optimization with AI. The use of AI makes it possible to increase the efficiency of mineral exploration [18]. This is confirmed by the results of the respective enterprises. Goldspot Discoveries Inc. Based on the use of an innovative approach to mineral exploration using AI, it was able to predict 86% of the existing gold deposits in the Abitibi region of Canada, using data from only 4% of the total area. The Goldcorp mining corporation, working with IBM Watson, was able to process vast arrays of geological information in search of deposits to select the best possible targets for exploration. The Australian iron ore mining company, along with other mining companies, has begun using machine learning algorithms to analyze geophysical and satellite data to predict the location of mineral resources with greater accuracy than ever before. This makes it possible to focus geological exploration work on the most promising areas, which significantly reduces the time and costs of searches.

Work efficiency thanks to automation. AI has a significant impact not only on exploration, but also on improving the efficiency of mining operations, such as autonomous drilling rigs, loaders, and trains. For example, Rio Tinto [19] (British-Australian multinational company) is a leader in using autonomous trucks to transport ore, which are about 15% cheaper to operate than trucks that require a driver. In Canada, companies such as Vale and Cameco [20] are using autonomous vehicles and drones to monitor and manage mining operations. These intelligent machines can work in extreme conditions without endangering the lives of employees. Autonomous trucks and equipment used in base metals

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and uranium mines can operate around the clock, increasing operational efficiency and minimizing the risk of human error.

Advanced security monitoring algorithms. Mining is an industry with many fatal accidents. It is listed it as one of the world's most dangerous occupations due to the potential for explosion, crushing or electrocution injuries [21]. Mining deals with many on-the-job deaths, so this element of the job should be given special attention. To ensure the highest standards of accident prevention, mining companies use technologies such as digital twins, IoT and computer vision. Thanks to this, mines can maintain proper operation, which is impossible without the use of modern technologies. Some of the methods used are wearables when the miners wear special suits with IoT sensors hidden in the material that constantly analyze the state of health of the employee. They also detect any unwanted actions that could lead to a crash. In South Africa, where gold and diamond mining are critical to the economy, the use of AI for security monitoring changes the approach to risk management. Artificial intelligence-based systems analyze employee biometric data in real time, predicting fatigue and potential health risks. This allows preventing the accidents and increasing the overall level of safety in difficult mining conditions. Another method is Thorough Tec – this is a system based on the principle of a digital twin: it is a simulator that supports the detection of inappropriate human behavior (which can lead to an accident) and allows early detection of threats.

Optimization of water consumption. Chile, being the largest copper producer in the world, faces the challenge of sustainable water management. AI systems are used to monitor and optimize water consumption in mining processes. Intelligent algorithms analyze data about water consumption in real time help to reduce waste and maximize the efficiency of using a valuable resource.

While these examples demonstrate the potential of artificial intelligence in the mining industry, the industry still faces challenges in integrating new technologies, such as ensuring data privacy and persuading workers to change. The key to future success will be continued investment in training, technological development and building trust between employees and new systems. As such, AI becomes an integral part of the mining industry, and its role will only grow. Thanks to continuous technological advances, the future looks bright for the sector, which is becoming more efficient, safe, and sustainable.

Based on the above, the purpose of the article is to research the directions of using AI in the activities of mining enterprises and build a model of integration of sensor, processing and control technologies that use neural networks in the information system of the enterprise to increase its efficiency.

3 Research methods

Content analysis was used to achieve the goal. With its help, the types of work are determined, for the effective use of which it is advisable to use artificial intelligence. The basis for finding ways to use artificial intelligence technologies are the results of research published in articles on this topic, as well as information from the official websites of companies engaged in the implementation of AI in the activities of mining enterprises [16, 22].

To build a neural networks implementation, the analysis of the main characteristics of neural network systems was used in the information system of the enterprise, and the description of their dependence was studied.

The volume and accuracy of information is an important resource component of building neural networks. The use of such technologies of information accumulation as sensors and controllers allows us to receive and process data within the database. Ielected parameters characterizing the activity of individual equipment, for the assessment of the performance of which the sensor is used. Hence, the increase in the number of sensors allows to accumulate more information, to estimate the parameters of the equipment's operation, and therefore, the more parameters it is possible to estimate, the easier it is to model the behavior of the object. This dependence can be represented using formula (1):

$$M_p \to \max_{\inf(p)}, \tag{1}$$

where M_p is the effectiveness of the model, which depends on the amount of information about the operation of the object.

From this, it can be concluded that the potential of using neural networks to control the efficiency of equipment, processes, etc. depends on the ability to use sensors and process the received information about the parameters of the equipment. And this, in particular, is possible under the condition of automating the operation of the equipment. Thus, we can conclude that the effectiveness of the use of neural networks for evaluating the performance of various types of work at the enterprise depends on the level of its digitization, which within the scope of this article we propose to calculate using formula (2):

$$D_p = \frac{Q_a}{Q_{n.a}} \to 1, \tag{2}$$

where D_p is the level of production digitization; Q_a is the amount of automated equipment; $Q_{n.a}$ is the number of non-automated equipment.

To process the received information about the experience of using AI intelligence in the activities of mining enterprises, the method of simulation modeling using Python software was used.

The formula for calculating the accuracy of the AI implementing into the information system model is:

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN}, \tag{3}$$

where TP is the true positives: instances that are correctly classified as positive by the model. These are instances where the actual class is positive, and the model predicts them as positive; TN is the true negatives: instances that are correctly classified as negative by the model. These are instances where the actual class is negative, and the model predicts them as negative; FP is the false positives: instances that are incorrectly classified as positive by the model. These are instances where the actual class is negative, but the model predicts them as positive (type I error); FN is the false negatives: instances that are incorrectly classified as negative by the model. These are instances where the actual class is positive, but the model predicts them as negative (type II error).

The formula for neuron network efficiancy can be represented by 4PL equation:

$$y = d + \frac{a - d}{\left[1 + \left(\frac{x}{c}\right)^b\right]}, \tag{4}$$

where a is the theoretical responce at zero concentration; b is the slope factor; c is the mid-range concentration (inflation point); d is the theoretical response at infinite concentration.

4 Research results

The implementation of AI is based on the application of neural networks, which are used to solve the following types of tasks:

– the ore extraction processes efficiency increasing;
– prediction accuracy of resource estimation;
– optimization of equipment maintenance schedules;
– reduction in operational costs etc.

The task of implementing AI in the company's activities is based on an individual approach, as it requires considering the characteristics of the company's activities, the level of its digitalization, access to the latest technologies, the level of professional skills of employees, etc.

The article proposes a model for integrating artificial intelligence technologies into the information system of a mining enterprise (Fig. 1). Its consideration will help to better understand the possibilities and potential of solving various tasks by the mentioned enterprises.

The model describes an information system that allows monitoring and controlling the processes of using autonomous trucks for mining, loading, and transporting ore. An important component of this model are sensors that read information from equipment that is equipped with appropriate outfit that perceive surrounding information. In this model, it is proposed to use sensors that read tires pressure, fuel level, distance and other valuable data for object positioning in space. In case of exceeding the set norms of the indicators read by the sensors, the system should alert the operator who is monitoring the mining process in the mine. As an additional part, separately connected network with auxiliary equipment such as generators, pumps, compressors, lighting, ventilation units and elevators, as well as information about the status of the equipment (machines), etc could be. Information from sensors in particular from the drilling machine, the loading machine and the transport machine in the form of telemetry data, is sent to the information system of the enterprise with the help of a wireless transmitter that covers the operational area. Next, the data is transferred to the control zone, where, in turn, it is analyzed. Based on the received data, appropriate decisions are made about maneuvering and performing certain operations, as well as regarding machine maintenance. In some cases, systems of laser correction of sectors of the machinery are added to the information system.

The collected information is the basis for the formation of neural networks that can be used in the management of the processes of the mining enterprise both underground and on the surface. This use of AI allows predicting accidents, accidents, traffic stoppages, coordinating vehicle movement routes and, if possible, optimizing movement.

It should be noted that the effectiveness of the model depends on the amount of information that enters the information system. Such access is provided with the help of sensors and sensors. Let’s pay attention to them. The sensors on the autonomous vehicle include:

– positioning and navigation sensor;
– tire pressure sensor;
– fuel sensor;
– inertial device;
– lidar;
– panoramic camera;
– software module;
– anemometers (for individual cases.)

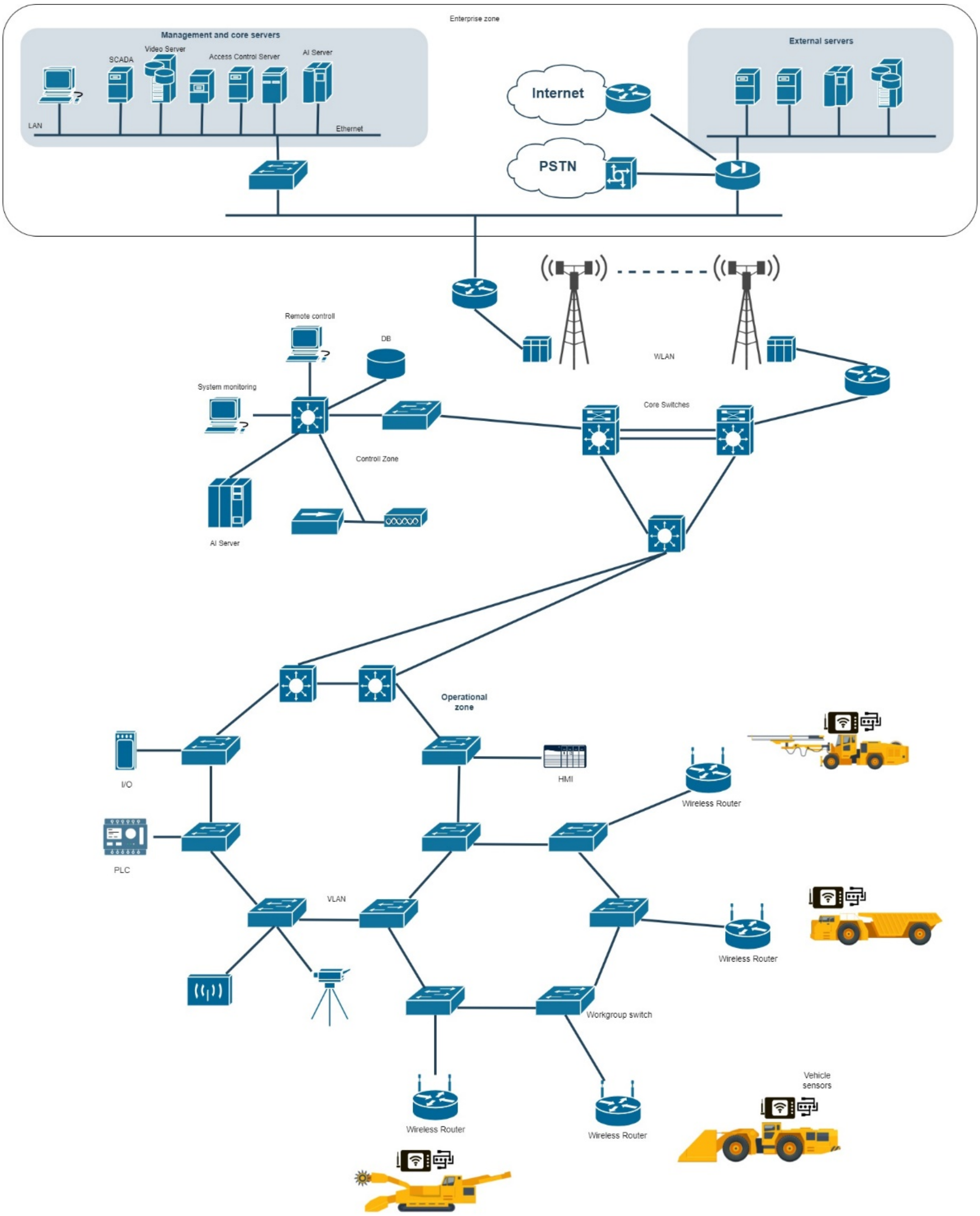

Fig. 1. Description of the information system of a mining enterprise using AI technologies Source: author's development.

Employees who are equipped with appropriate equipment can also be connected to the information system, which will allow monitoring their health and well-being. Relevant information is fed to the control area and monitored and analyzed by AI. Thus, the described processes make it possible to integrate AI into the information system at the operational level.

The description of the architecture of the considered information system with integrated AI is also worthy of attention. This information system distinguishes 4 main zones:

– corporate zone (Ethernet-Lan);

– intermediate area (WLAN);
– control zone;
– operating area (VLAN).

In the control area, there are monitoring and remote-control operators, generated data of the operational area, computing equipment, and servers on which neural networks are installed, and which are important for the operational management of the area. Enterprise and operational zones are connected to each other by wireless communication stations. In turn, the operational level can be divided into upper (above ground) and lower (underground). At the transition to the operating network, there are industrial switches.

Note that each of the lower-level networks must be ringed, so that in the event of a potential communication breakdown in the network, the system does not lose the ability to transmit data. In particular, a ring network topology is used to avoid loss of communication in the operational area. An information input/output device, a human-machine interaction device and a controller for managing local processes are connected to this network. From Fig. 1, we can see that a network with wireless routers is also connected to this ring, which allows real data to be read and transmitted to the control zone.

Thus, the built model allows for remote and autonomous operation of equipment at mining enterprises, which allows solving several tasks that were discussed above in this article. To reduce the number of neural network errors, it is necessary to consider many various parameters that directly depend on the level of digitization of the enterprise to formula (2). The application of the coefficient of accuracy of the solved tasks to formula (3) can serve as a criterion for evaluating the effectiveness of the application of neural networks in the enterprise's information system as a result of evaluating the effectiveness of the performance of various types of enterprise’s work. The evaluation of the efficiency of the neural network must be done according to formula (4). The efficiency function of the neural network with the improvement of the information analysis algorithm in the network leads to dependence represented by to formula (4) (Fig. 2).

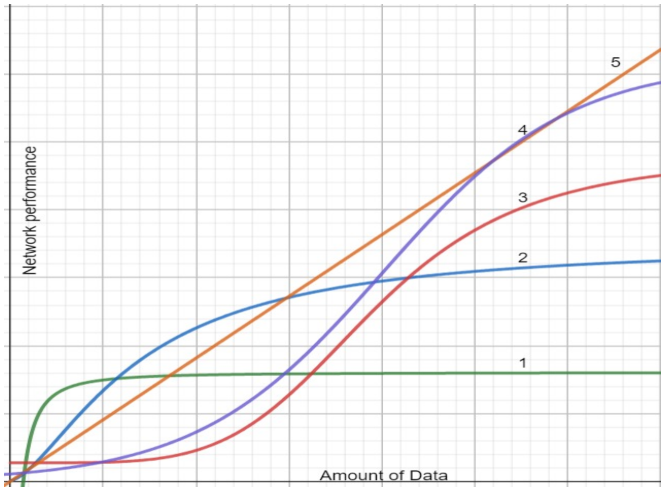

Fig. 2. Information system with integrated AI model performance dependency: 1 – simple statistical learning; 2 – shallow neural networks; 3 – medium neural networks; 4 – deep neural networks; 5 – asymptotic value.

This graph (Fig. 2) illustrates the relationship between the efficiency of the neural network and the amount of data used for its training. With the expansion of the volume of mine activity, the number of devices increases. This, in turn, will cause an increase in the load on the information system, as well as increase the amount of data required for the formation and functioning of neural networks. The function of the efficiency of the neural network with the improvement of the information analysis algorithm in the network is heading towards a linear dependence. Represented plots have hight correlation with the real efficiency dynamics. By applying scaling coefficients, formula (4) can have hight coefficient of determination and can help to determine an efficiency for appropriate model configuration. The considered example allows us to expand the vision of applied application of AI tools to improve the operations of mining enterprises. The obtained results require additional testing at industry enterprises and are a promising direction for our further work.

However, it should be noted that the experience of companies that use AI in their activities indicates a few reasons that prevent the successful implementation of AI. In particular, according to the results of a sample survey of 7.502 enterprises worldwide, conducted in 2022 by Morning Consult on behalf of IBM, the following obstacles were identified [23]: 34% of surveyed enterprises consider limited skills, experience or knowledge of AI as an obstacle; too high a price (29%); lack of chip platform tools for model development (25%); projects are too complex or difficult to integrate or scale (24%); and high data complexity (24%). Two-thirds of the companies surveyed are implementing or planning to use AI to achieve their sustainability goals.

5 Conclusions

The article examines ways of using AI in the activities of mining enterprises. Statistics on the use of AI in mining indicate that this technology is expanding its scope of application. Based on the analysis of literary sources and the generalization of information about modern trends in the use of artificial intelligence in the development of mining enterprises, the article builds a model of AI integration into the information system of a mining enterprise. Note that this model considers the specifics of the work of a mining enterprise, but it can be used for other enterprises based on the construction of a specific architecture and considering the specifics of work. For the mining enterprise, four zones have been allocated, which allow the distribution of zones of responsibility and types of processes in accordance with the tasks to be solved.

The proposed model allows analyzing its structure, characterizing the operations supported by it, as well as evaluating the possibilities of potential implementation of neural networks, development and application of corresponding indicators for measuring their effectiveness. Thus, AI technologies are expanding their scope of application and are potentially aimed at increasing the qualitative and quantitative indicators of operational activity, increasing the efficiency of management, the quality of work, the level of safety and service.

We will carry out further research in the direction of researching the accuracy and efficiency of the use of neural networks, since conducting such calculations requires a significant amount of information about the activities of enterprises.

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