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IMPLEMENTATION OF DIGITAL TECHNOLOGIES AT BLENDING STOCKPILES IN OPEN PIT MINING

Industry 4.0 is a set of innovative technologies theoretically and practically applicable in industrial processes. The RFID system, a radio frequency identification technology, has become one of such innovations. The absence of ore tracking in the mining industry entails an increase in dilution and complicates mineral blending logistics. Currently, mining companies are starting to implement Industry 4.0 projects to optimize production but percentage of such companies in the industry is yet small. There are very few scientific works related to the application of ore tagging, and there is little data on the use of this technology in the mining, so the implementation of RFID tagging system in the mining industry is an urgent task to study. The research methods were the review of scientific literature and the analysis of digital products for graphical representation of blending stockpile optimization. As a result of the study, the possibility of practical application of RFID technology was considered, and the scheme of ore tagging in stockpiles was justified. The work provides useful information for implementing RFID technology in the mining industry. Open pit mining uses surveying to track and analyze stockpiling processes but this methodology is directly dependent on human factors and offers insufficient information about ore whenever. These production problems can be fixed by implementing an RFID tagging system, which indicates the practical significance of the study.

Keywords: *Open pit mining, open pit mine digitalization, tagging, ore storing, ore blending, sound management, ore grade*
DOI: *10.17580/em.2025.02.17*

Introduction

The mining industry is one of the oldest industries and is important in the economy of a country [1, 2]. In recent years, there has been a slight decline in the development of the mining industry in the Russian Federation due to the difficult organization of supplies of modern equipment of foreign manufacture and a decrease in demand for mining raw materials from some companies. However, the development of equipment and technologies of domestic production can compensate for the negative aspects and lead to the advance of the entire mineral resource sector [3]. Modern conditions of global economy create new tasks for the mine management: rationalization of production chain, implementation of innovative technologies [4, 5].

In the 21st century, global companies, including mining industry, follow programs of sustainable economic development, which indicates the necessity to modernize production with the implementation of information technologies [6, 7].

Due to the fact that technosphere safety is one of the main vectors of development of most modern mines, the heads of mining companies focus on reducing the number of employees working directly in hazardous areas of minerals mining, processing and transportation [8]. The preservation of human capital has a positive effect on the economy of a mine, as well as reduces the number of accidents [9, 10].

In the modern world, mining and digital technologies are inseparable from each other. Creating a 3D model of the occurrence of ore bodies for the design of open-pit and underground mining operations, evaluating mineral reserves, tracking tire wear of haul trucks, artificial intelligence in managing processes at mines—digital products simplify, improve and promote efficiency of mining [11, 12]. One of these technologies is RFID system.

Radio frequency identification (RFID) is a technology that uses electromagnetic fields to transmit data. It can also be attributed to the process of using wireless broadcast technology to collect and restore data. RFID is a unique technology for automatic identification and data collection (AIDC). It is considered by many scientists and experts as the Internet of Things, which indicates the possibility of a potential user to find out information about a marked object by viewing a database entry or an Internet address that corresponds to a certain RFID.

The main objective of the study is to substantiate the use of RFID-based ore tagging to increase the efficiency of an open pit.

When developing mineral deposits via open-pit mining, ore storing is the final technological process. With a relatively constant percentage of a valuable component, storing means placement of ore for temporary storage. In case of separation into rich and low-grade ores, it becomes necessary to create a blending stockpile, which affects productivity of mines.

The research used the literature review, and the analysis of theory and practices of ore tracking in open-pit and underground mining [13]. During the study, specialized software and graphic editor were used to substantiate the ore tracking system.

Results

This study justifies introduction of the implementation of ore marking via RFID tagging system. Rationalization of production processes using digital technologies has particular importance in modern mining [14, 15]. The implementation of digital technologies such as RFID requires significant investments and can have positive impact on production [16].

RFID technology is of particular interest due to its potential and high efficiency in the transformation of mines [17, 18]. Now is the right time for RFID technology to become a breakthrough in the mining industry [19, 20].

Some studies consider the use of RFID tags as a control factor for monitoring ore transportation along belt conveyors. One of the most important features of the use of RFID is the relationship between its industrial application and the logistics sector.

Additionally, it is worth noting that RFID tags used to track and control ore flows have the ability to uniquely identify and exchange data, which significantly increases the efficiency of managing the processes under study [21]. This technology makes an important contribution to

Fig. 1. RFID tag dumping into haul truck

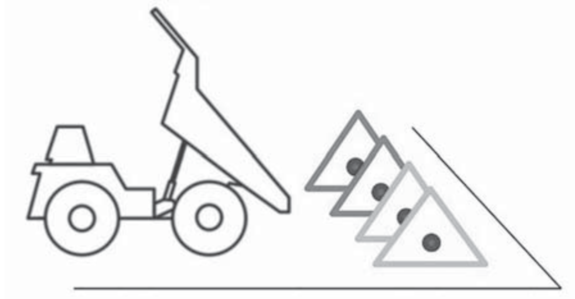

Fig. 2. Haul truck unloading at rich and low-grade ore stockpiles

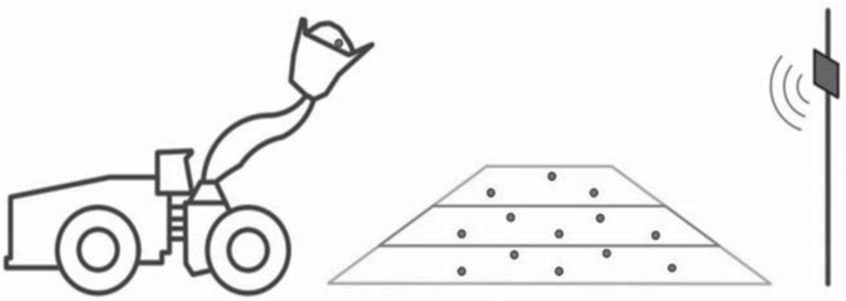

Fig. 3. Ore concentration blending

the rational operation of mines, leading to increased productivity and reduced costs.

Currently in the Russian Federation, RFID is not used in mining, despite the numerous capabilities of this technology. It is worth pointing out that the use of ore tracking can significantly simplify blending stockpile management.

A special feature of RFID tags is the high level of dust and moisture protection. They can be made in a sturdy plastic case, which allows operation in difficult climatic conditions. RFID tags are also suitable for operation in surface and underground mines. However, research is needed to assess effectiveness, potential and direction of application of this technology in the mining industry.

The use of RFID technology will lead to changes in mining operations, for example, drilling and blasting, transportation and storage of ore [22].

Real-time data collection and information exchange between production and investors, implementation of new business models and practices such as inventory management, special-order-supply chain management and reverse logistics will increase attractiveness of the entire mining industry. It is expected that the new opportunities provided by RFID technology will bring significant profits and make mining processes more efficient and sustainable.

RFID system

Typically, radio frequency identification technology consists of electronic tags, a reader, an antenna, and a computer with software to control the work of RFID equipment.

The RFID system consists of four components:

1. An electronic tag consisting of a microprocessor chip (it is an integrated circuit with memory). This microprocessor chip is implanted into a physical object to be recognized.

2. A reader is a device that reads RFID data without any physical contact with the tags. The connection between the reader and the tag allows recording information about the location of objects and transfer it to the server via computer network, which makes it possible to track the movement of objects.

3. Antennas are the channels of data communication between the reader and the tag. They have a reading range both on the side and in front of the antenna. The structure of the antennas' location is important for monitoring the coverage area, as well as for the efficiency and accuracy of communication between the tags and the reader.

4. Computer with software for RFID equipment management, data screening and interaction with corporate applications [23].

Discussions

If it is necessary to average ore grade, blending stockpiles are created at mines, to mix different grade ores. As a result, ore of averaged quality is supplied to an ore-processing plant [24, 25]. When carrying out organizational and technical measures to effectively blend ore, the main role is played by the geological and surveying service of open pits, which must timely supply engineers with initial data and relevant documentation, and should control the ROM ore quality.

Ore storage has its disadvantages: due to the human factor, data on location of certain quality ore in stockpiles is lost. As a result, the processing plant either faces unplanned downtime or has non-blended ore in supply. Processing equipment is selected for a certain ore grade. Therefore, if rich ore is received for processing, a significant part of it can be sent to tailings, since the equipment can fail. If poor low-grade ore is received for processing, it can go entirely to tailings without any residue in concentrate. As a result, the lack of blending leads either to a low-grade or to an oversaturated concentrate, which also leads to useful mineral loss—all this becomes the cause of pecuniary losses of mines.

Modern software allows tracking and coordinating travels of cutting, loading and haulage machines, performing automatic open pit dispatching system. Consequently, when combining the data of geological exploration, surveying and position fixing of excavation equipment, it becomes possible to provide each haul truck with its own

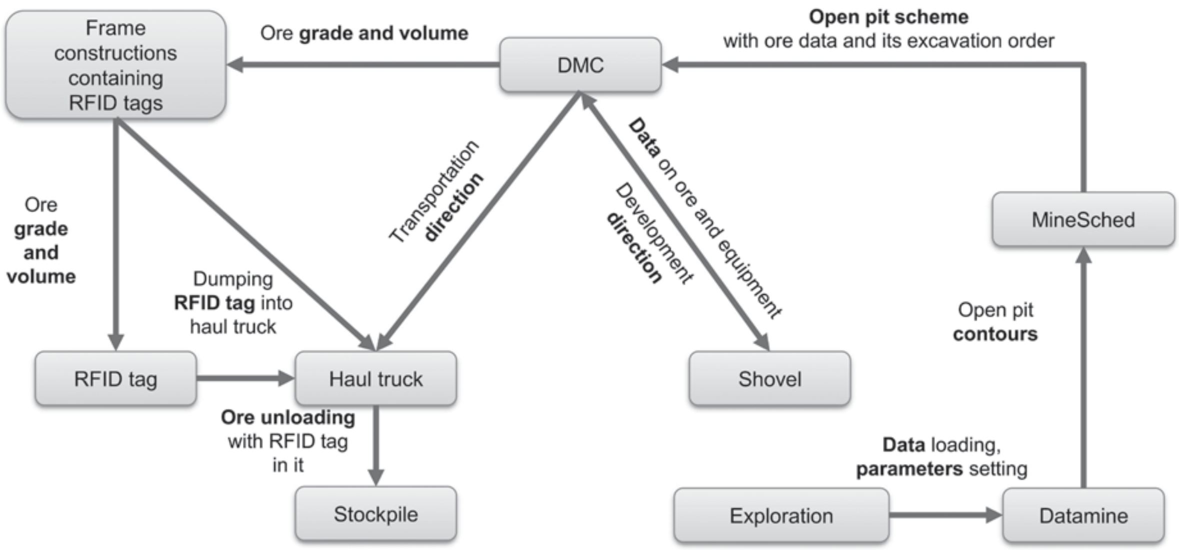

Fig. 4. Path of data on mineral concentration

unique data containing information about the grade and volume of ore being transported [26, 27].

Complying with the above conditions, the ore tracking technology sticks to the following flow sheet. Mineral data is transmitted to and stored in production management centers. Frame constructions containing RFID tags and programmed to transmit information about the ore transported by each haul truck to RFID tags are installed at the entrances to the ore blending areas. RFID tags located inside sturdy plastic cases are dumped into each haul truck passing under the frame (**Fig. 1**). When unloading haul truck bodies, RFID tags are left in the ore piles (**Fig. 2**). Ore from rich and low-grade ore stockpiles is transported by a front loader to the blending stockpile and is levelled out in layers with different ore grade by dozers (**Fig. 3**).

Antennas are placed along the perimeter of the blending stockpile, scanning the territory allocated for ore placement (see Fig. 3). Due to the binding of antennas to coordinates and the ability to determine the distance between RFID tags and antennas by scanning the blending site each RFID tag, in addition to data on the ore grade, gets its coordinates. Consequently, antennas and modern software as a result of ore tagging allow processing management centers to obtain 3D models of both stockpile of rich and low-grade ores, as well as the blending stockpile itself. Moreover, this 3D model has a separation by ore grade, which makes the ore blending process more accurate.

The process flow diagram of transmitting information about the ore grade from the beginning of the exploration of the deposit—geological exploration—to ore storage, with the use of software systems such as Datamine and MineSched at the deposit, is shown in **Figs. 4 and 5**.

The life cycle of RFID tags ends at the bending stockpile. During ore processing, both RFID tags themselves and plastic cases, containing the tags, are crushed and disintegrated with further mixing with the tailings.

Economic efficiency

While searching for ways to rationally average ore quality at the inlet to processing plant, RFID tag system was considered. By placing tags in the body of a haul trucks using the frame constructions, the mining company receives a source of information about the grade and location of a certain volume of ore. With the help of RFID tags, it becomes possible to carry out a structural analysis of stockpiles at any time, and to create an accurate 3D model of the stored rocks. All this makes it possible to regulate and optimize the processes of storage, thereby increasing the efficiency of the processing plant.

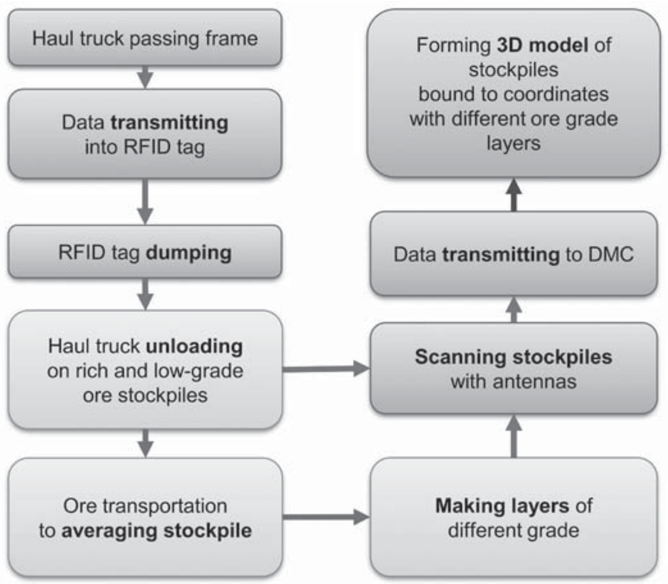

Fig. 5. Ore tagging flow chart

Table 1. Cost structure of the investment project

Cost item	Quantity	Cost, million RUB	Sum of expenses, Million RUB
Pilot project, pcs	1	40	40
RFID tags, pcs per year	40 000	0.0133	532
RFID antennas, pcs	30	0.2	4.6
RFID tablet PC, pcs	3	0.8	2.4
Electric power supply, pcs	1	5	5
Frame constructions, pcs	2	1.8	3.6
Software, pcs	1	1.5	1.5
Total amount			589.1

The study also considers the economics of RFID ore tagging. A diamond deposit with and annual production capacity of 5.200 Kt was chosen as the object of research. The economic justification was carried out taking into account the work of the mine, which ensures an

Table 2. Economic substantiation of investment project

Item	2023	2024	2025	2026	2027	2028	2029
Annual diamond output, thousand carat	4680	4820	4820	4820	4820	4820	4820
Revenue, million RUB	263 740	271 650	271 650	271 650	271 650	271 650	271 650
Revenue change, million RUB	0	7910	7910	7910	7910	7910	7910
Net proceeds, million RUB	32 420	33 390	33 390	33 390	33 390	33 390	33 390
Cash flow (increase in earnings only caused by the project, million RUB	0	975	975	975	975	975	975
Investment, million RUB	589	532	532	532	532	532	532
Net proceeds, million RUB	–589	443	443	443	443	443	443
Total cash flow, million RUB	–589	–146	297	739	1182	1625	2067

Table 3. Substantiation of economic efficiency of the investment project

Item	2025	2026	2027	2028	2029	2030	2031
Cash flow, million RUB	0	975	975	975	975	975	975
Investment, million RUB	–589	–532	–532	–532	–532	–532	–532
Net proceeds, million RUB	–589	443	443	443	443	443	443
Discount rate, %	15						
Discount factor	1.00	0.87	0.76	0.66	0.57	0.50	0.43
Net present value, million RUB	–589	385	335	291	253	220	191
Total net present value, million RUB	–589	–204	131	422	675	895	1087
Payback period, year	2.33						
Internal rate of return, %	72						

increase in annual diamond production by 3%, by reducing dilution and technological downtime. As a result, an investment project was drawn up for the introduction of RFID tags in production.

It is particularly worth noting that the use of this technology is of interest at this time in difficult climatic conditions, as well as in case of difficult logistics between production and the nearest settlements, which can ensure the delivery of the required mechanisms, equipment, consumables [28].

The first thing that needs to be assessed during implementation is the cost structure [29, 30]. It is very important to bring a pilot project in order to evaluate the operation of the system and select RFID tags and equipment suitable for the operation conditions of tagging in mining production. For the successful operation of the system, it is necessary to purchase tags and equipment for tracking and dumping the tags into the haul trucks transporting ore. RFID tags in sturdy plastic cases with a high level of dust and moisture protection are convenient for use in difficult climatic conditions. Ore stockpiles should be equipped with antennas that scan rocks. It is also necessary to carry out communications making the operation of the antennas possible. The detailed cost structure is presented in **Table 1**.

The second thing that needs to be done before the implementation is the economic justification of the accepted project [31]. When considering the project, 2023 was adopted as the year of implementation. Starting from 2024, it is expected that diamond production will grow thanks to the ore blending process control. The main production costs of the project will be depreciation of purchased equipment and purchase of consumables: RFID tags. A detailed calculation of production, revenue and costs of production processes, taking into account losses caused by the need to remove overburden, is presented in **Table 2**.

The third step is analyzing the project economic efficiency as in **Table 3** [32, 33]. The key indicators were a reduction in cash flow by a discount factor, which includes a risk-free rate and a risk premium of 15% annually. The total net present value of the project will be 1182 million RUB on the sixth year since the project implementation. The payback period of the project will be two and a half years. The internal rate of return of 72% is higher than the discount rate, therefore, the project generates income, which indicates the efficiency of the project being implemented and the reality of its implementation into production [34].

When using RFID technology, it becomes possible to determine what type ore is being transported to stockpiles, as well as to locate the ore with the required grade. In addition, there is an RFID-like tagging system known as microdot, which uses nanochips to transmit and process data. In the oil and gas industry, RFID tags are used to tag pipes and containers [35]. However, in the mining industry of the Russian Federation, there is no similar application of this technology for the control over ore grade ore supplied to processing plants [36].

The RFID tagging systems have huge potential not only in ore storage. The use of this technology will lead to a breakthrough in the framework of the Smart Open Pit project, which in turn will have a positive impact on mine safety and production costs. It is also possible to note the prospects in other areas of application in mining, namely: tagging the clothes of employees to track movement and improve safety; tagging rocks in face area to provide more accurate data on mineral cutting.

Conclusions

As a result of the study, the use of ore RFID tagging system was considered and justified in order to rationalize ore quality averaging processes. The economic justification of the tagging flow sheet in the work was also carried out.

The use of RFID technology will improve efficiency of open-pit mining due to a more accurate determination of ore grade after blending.

As a result of the valuation of the investment project for the implementation of the tagging system, its economic efficiency was validated, therefore, companies will profit from the use of RFID tags.

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