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Directions for using the Blockchain technology in the raw materials industry

Introduction

The mining industry is beginning to use technologies which had been previously available only in the theoretical realm. The ongoing development towards a smart industry entails a number of studies and expert assessments, aimed to integrate knowledge from the mining and IT areas. The combination of these research areas leads to an increase in the value of both the companies implementing modern technologies and traditional companies that implement such applications in their value chain. Based on the analyzed articles, two main areas of consideration in the context of the extractive industry were distinguished:

- systems that track and secure the flow of data in specific mining processes;
- systems that monitor and secure information on processes which support the supply chain.

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In a modernized and automated industrial world, data authenticity and verifiability are becoming increasingly important. Technologies that guarantee increased trust and data traceability are gaining popularity.

A system like this is remarked on by Evsutin and Meshcheryakov who focus on the problem of data flow security between production workers in a mining company, proposing a virtual data tagging system (Evsutin and Meshcheryakov 2020). Hua, Jiang, Sun, and Wu took the scholarly discussion a step further, analyzing a Blockchain-based peer-to-peer transaction system concerning people called energy prosumers as a case study (Hua et al. 2020). Samis and Steen write about the relevance and value of verified and validated data in their work (Samis and Steen 2020).

The use of modern technologies is also applied in another branch of the extractive industry. In their research, Helo and Hao try to approximate the problem of implementing Blockchain technology in supply chains using the method of immutable distributed ledgers (Helo and Hao 2020). Research into the use of Blockchain technology is also moving in the direction of improving warehouse management by using drones to collect data. Such a system was described by Fernandez-Carames in his publication on Blockchain technology to improve the transparency and security of the data transmitted by the system (Fernandez-Carames et al. 2018). When deciding to use modern technology to improve specific areas of business, companies need to look at the economic background.

Lu, Huang, Azimi, and Guo investigated the possible directions of using Blockchain technology capabilities in the fuel industry from an economic perspective, considering the two fastest growing technological regions: Europe and Asia (Lu et al. 2019). Klippel, Petter and Avtunes Jr. summarized the need for innovation management in today's mining industry in the context of globalization (Klippel et al. 2008). Research on the use of technology has also reached South America. In his work, Fernandez studied the need for innovation in the mining sector, taking the example of Chile, based on R&D expenditures (Fernandez 2020).

Building a competitive position and basing the development strategy on the organic growth of the company's value through conscious investments in modern technologies enabling the improvement of data verifiability makes economic sense. Hazari's research points to the development of Blockchain technology towards scalability, which directly translates into a reduction in the cost of implementations of such systems (Hazari 2020).

Considering the multidimensionality of issues related to the application of modern cryptographic technologies, the focus was on isolating and defining problems concerning the processes of tracking and verifiability of data in the mining industry. Current knowledge of the essence of Blockchain technology, its structure and characteristics was used for this.

1. The essence of Blockchain technology

In order to indicate the direction of the use of Blockchain technology in the mining industry, the research area was divided into three main segments. The first segment defines the essence of its function by applying the concept of decentralization, which supports processes related to security and the increase in transparency of transactions through a distributed structure. The basic theory of the process of adding a new block to an existing chain is then described. Due to the use of advanced cryptographic technologies that significantly affect the level of security of data flow, this process is the basis for consideration of the possibility of implementing such solutions in the mining industry. The third area aims to clarify the theory of block header extraction by solving the proof of work as one of the methods used in the technology under consideration (Christidis and Devetsikiotis 2016).

The target point of the following considerations is to indicate the directions of application of Blockchain technology in the mining industry by analyzing the possibility of its implementation on the basis of process conditions. Particular attention must therefore be paid to the essence of the function of such systems. Literature studies and analysis of solutions existing to date indeed indicate the multidimensionality of the technology in question (Atlamet et al. 2020), especially in the context of increasing contribution of the Internet of Things (IoT) to the global ecosystem. Multidimensionality also involves the ability to customize technology to solve a specific problem related to the aforementioned areas, such as data security and traceability throughout the data workflow. The decentralized structure that allows all participants in the process to verify the entered data, which significantly affects the level of security and transparency, is an important change within Blockchain technology.

1.1. Decentralization as a tool which helps secure data transactions

The flow of information in today's industry involves an enormous amount of minute-by-minute data processing. Its credibility is based on a process of verification and authentication. The mining industry is characterized by a high degree of process parameterization, for which data supplied in high quality and reliability is essential. This is because it has a real impact on the final + product, in this case the processed raw material.

The data in question is intended to be a carrier of information that is transformed into knowledge about a process. The main sources of data in mining processes are the machines by which extraction is carried out. Therefore, it is important to consider the extent, to which the data from the machines reflects the actual state of affairs and the state, in which it reaches the decision-making end user. For the most part, this is data provided from centralized systems, i.e., systems that rely on the decision-making of a central entity. It determines the ability to view data history, analysis, and the ability to accept a set of new data. The essence of the problem is the long path of information flow and the hierarchical nature of the structure.

Taking this into account, Table 1 traces the main differences between centralized and decentralized systems. The comparison was made based on a study by Fan and Liu (Fan and Liu 2020).

Table 1. Comparison of centralized and decentralized systems

Tabele 1. Porównanie systemów scentralizowanych i zdecentralizowanych

	Decentralization	Centralization
Presence of a third party in the transaction	no	yes
Independent decision-making	yes	no
Universal accessibility of transaction history	yes	no
Common ability to confirm transactions	yes	no

The most fundamental differences between centralization and decentralization are found in the area of common access to a given transaction. Universality in decentralization is a desirable phenomenon. Users in decentralization-based systems have access to historical data. Data in this structure is transparent and sensitive to any changes. Sensitivity to change is demonstrated by the general ability to confirm or cancel transactions. This opportunity provides a great deal of autonomy in decision making. It guarantees a direct flow between two parties to a transaction, where there are no intermediaries to interfere with the substance of the transaction.

A centralized structure is characterized by the unidirectionality of decisions. Unidirectionality stands for decisions that are made by the individual who is the only one in the

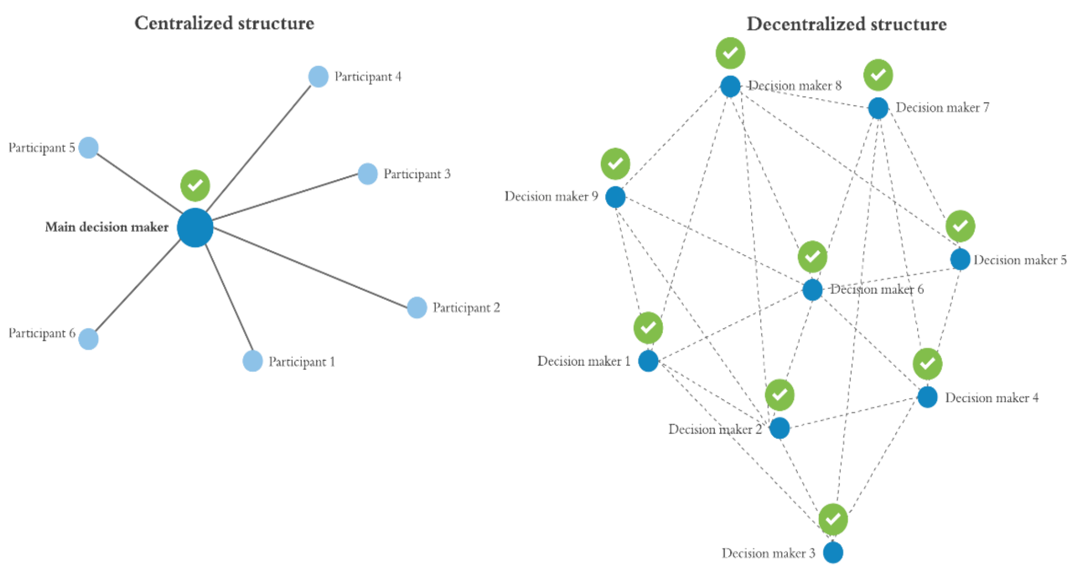

Fig. 1. Differentiating centralized and decentralized structure in terms of network decision-making

Rys. 1. Różnicowanie struktury scentralizowanej i zdecentralizowanej w aspekcie podejmowania decyzji sieciowych network giving commands and resources to the participants. This approach puts a lot of risk on the entire network. This risk involves leaving decision-making to only one participant, who, in a pessimistic scenario, could prove to be an easy target for hackers. Additionally, the process is slow and presenting a high load on server resources.

When it comes to a decentralized structure, we are dealing with a rapid flow of information. This involves using the resources of each participant. Additionally, decision-making in such a network is distributed. This reduces the risk of the pessimistic scenario assuming a hacker attack on the network, because, in order for the network to be taken over, the hacker must take over each of the computers that are involved in the chain. The differentiation of structures in terms of decision making is shown in Figure 1.

A data security mechanism based on decentralization is proposed by Ge, Liu, and Fang (Ge et al. 2020) in their research.

The idea of decentralization should be considered as the basis of Blockchain technology. This type of data dispersion allows one to realistically secure one's network against cyber-attacks. Additionally, its ubiquity results in high transparency, which is a key advantage when it comes to data flowing in from machinery. Based on the analyzed architecture, the basic idea of the discussed technology is described.

1.2. Blockchain structure

Decentralization involves the elimination of central transaction parties that are necessary to accept data validity. The mentioned elimination is the main premise of Blockchain technology. This enables networks to be created that allow participants to complete transactions without trusting each other. Such networks are referred to as trustless networks (Shetty et al. 2020). This is a specific type of network in which individual nodes do not need special permission from a central arbitrator. They can therefore make independent decisions consistent with the interests of the entire network. Decision making is therefore distributed over the entire network and not just focused on a single arbitrator (Ling et al. 2019).

In essence, Blockchain is a cryptographically secured, distributed database. Its operation is based on the continuous addition of record strings (Drescher 2017). Records, otherwise known as blocks, are stored in various nodes that are continuously verified. Each record contains basic information about the transactions performed and the block size. Additionally, each block contains a header, which is a unique identifying element consisting primarily of the Merkle root. This root represents a shortcut that is able to identify the block without error. The header also contains information about the previous block and the value of the nonce, which is a random or pseudo-random number that is generated only once. This number is used to solve the equation that is the proof of work (Dhillon et al. 2018). The proof of work is solved by miners who, by lending their computing power in progress, modify the nonce to solve the task. A miner who solves the proof of work correctly can expect to be paid in virtual currency (e.g. Bitcoin).

Proof of work is one of the most popular consensus mechanisms, involving hash computations to find a value that satisfies a given requirement (Ren et al. 2020). By solving a proof of work, a block can go into the block chain. This process is illustrated in Figure 2.

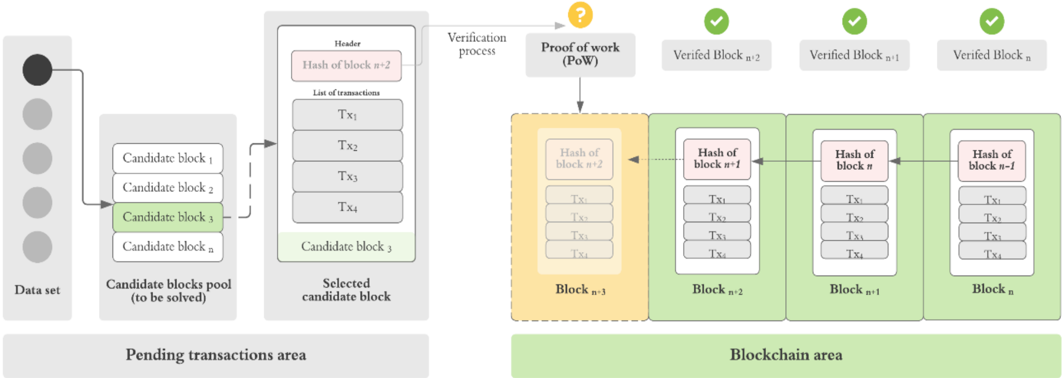

Fig. 2. Simplified scheme for adding new transactions to an existing blockchain with proof of work

Rys. 2. Uproszczony schemat dodawania nowych transakcji do istniejącego łańcucha bloków z dowodem pracy

Adding new transactions is done in two main areas – the waiting room, where transactions are waiting to join a block, and the blockchain area. The process begins with miners, or network participants, collecting information about transactions that have been executed recently, located in a distributed fashion, in the waiting room. These transactions are collected in a pool and are waiting to be added to the existing chain. The existing chain consists of already verified blocks that have a header, a transaction list, and a hash of the previous block.

In order for a block to be added to a chain, a header must be found for it. Adding a header is a process in which miners compete with each other to solve an equation to find the correct value. This value is also called the target value. To find this value, its hash is extracted from the existing preceding block header and added to the nonce value. Matching the hash value to the target value is done by modifying the nonce so that the hash value is less than or equal to the target value. If the equation is satisfied then the hash is used as a header for the candidate block. Making headlines not only entails the opportunity to add a block to the chain, but also a reward for the winning miner in the form of cryptocurrency. Completion of a proof of work involves the use of the computing power of the miner's machine, hence the remuneration for their work. Additionally, in order to solve the proof of work, the miner must generate more and more hash values due to the increasing nonce value.

A block which was already added to the chain has its own structure, in which the unique elements include the aforementioned header and the transaction list. These two areas determine the block and give it special characteristics. For the header, the special sign is primarily the Merkle root, the difficulty, and the nonce by which the block was created.

For a transaction list, the key elements are inputs and outputs. In practice, these are documents which have been signed and attached to the block, which confirm the transaction between the parties. In addition, the transaction list includes a delay, which is the time it takes for a transaction to be accepted. A single transaction is merely a component in the overall chain, which is largely based on Merkle's notion of trees.

1.3. Application of Merkle trees in solving a proof of work

The Merkle tree is used to link transactions using a hash (Krishnapryia and Greeshma 2020). Linking is important for transaction verification. Verification must be done as efficiently and meticulously as possible. The Merkle tree is designed to streamline and provide transparency to this process. It also helps in optimizing the blockchain in terms of size.

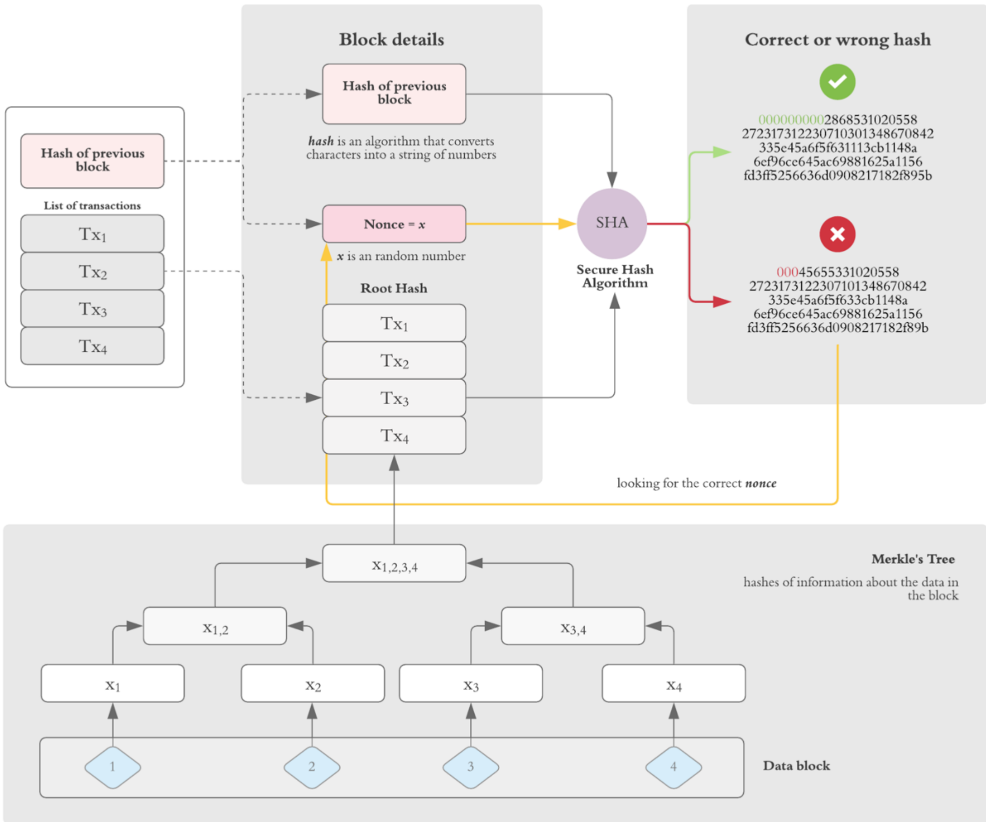

Fig. 3. A simplified diagram for adding a header to a pending block by solving a proof of work considering the Merkle tree problem

Rys. 3. Uproszczony schemat dodawania nagłówka do bloku oczekującego poprzez rozwiązanie dowodu pracy z uwzględnieniem problemu drzewa Merklego

The essence of Merkle's root lies in the ease of identifying transactions. This ease is based on the information given at the top of the tree, about the stored transactions. We call this information a shortcut which is created step by step from the lowest layers of the tree, i.e. the transactions. The transaction shortcut x1 is combined with the transaction shortcut x2 using a function calculation for the two transactions. The shortcut x1 x2, in turn, is combined with shortcuts x3 and x4. This procedure allows all four transactions to be combined into a single digest that informs about the transactions involved (Becker 2008). The process described is shown in Figure 3.

Application of the Merkle's root method allows for simple verification of transactions as early as the proof-of-work resolution stage, where the collected transactions are subject to initial verification. The list of transactions structured in such a way allows one to easily find transactions in the entire pool, which may amount to even several million contracts. The shortcut method also enables easier management of the chain itself, which in the process of adding subsequent blocks grows to several gigabytes in size, being impractical from the point of view of distributed system performance. The simplicity regarding data security and verification may provide a rationale for the use of distributed technologies in mining and energy-related fields, often struggling with information reliability.

2. Blockchain technology implementation areas

The existing knowledge of Blockchain technology allows us to identify potential areas where its application will significantly affect industrial processes. For the mining and energy sectors, the opportunities for technology implementation lie in two main areas. The first is to secure the flow of information in both internal communication (safeguarding against manipulation of raw material data) and external communication (safeguarding the flow of transaction information between the company and the customer). The second area that stems from the first one is the ability to implement Blockchain technology as a system for monitoring processes and tracking a particular raw material (treated as a product) through its life cycle, from exploration to sale.

2.1. Securing data flow within manufacturing processes

Data security involves the use of methods that address today's needs for information quality and sensitivity. We can divide the flow of business data by where it is accessed into internal flow and external flow.

The data listed below requires additional safeguards due to its confidentiality and sensitivity. A complete classification of data flow in mining companies is shown in Table 2.

The data presented is subject to natural growth over time, which may cause its security to be weakened. The development of technologies related to M2M (Machine to Machine) communication brings both new solutions and results in security gaps for the transmitted data (Kimani et al. 2019). These gaps, or vulnerabilities, can occur both at the level of hacking attacks (at the level of external data flow) and the effects of using data deemed to be incorrect or incomplete (within the company's internal flow). Blockchain can therefore be a technology that, by combining the functionalities of transaction exchange, data processing and storage, and modern cryptographic algorithms which safeguard the transactions performed, will secure the trust gap against analyzed data in various types of technological processes (Ren et al. 2021).

Table 2. Classification of data flow in mining companies by location of data access

Tabela 2. Klasyfikacja przepływu danych w przedsiębiorstwach górniczych według lokalizacji dostępu do danych

Internal flow	External flow
Methods and practices used	Intercompany contracts
Raw material parameters	Order volume data
Financial data	Product quality data
Know-how	Commodity transactions

The main and necessary internal technological processes in mining include processes involving machinery, and within them is a range of information necessary for the proper implementation of each of these processes. Modern machinery used in mining are beginning to collect more and more accurate data on actual machine wear, work levels, and part usage (Wu et al. 2019). The implementation of Blockchain technology can enable the secure and transparent flow of data from the machines to the end user who decides about the process. The user is given full access to the changes that are made during dispatch, so they can monitor the transactions that occur between the machine, the machine operator and the end user in real time. Such a possibility, using an additional board programmed for the Blockchain environment, was presented by Korb in his experiment, which clearly shows an improvement in security and a cease in tampering compared to existing systems (Korb et al. 2019).

In the context of considerations for Industry 4.0 for the mining industry, the use of technology can be crucial in providing process information. Each process can be described using specific criteria, which are divided into three main categories – mining-geological, technical and economic. The main processes involving machines, analyzed for key data collection, can be classified as:

1. Corridor excavation (cutting, loading, casing) – involves extraction per unit of time per shift or day, for example, with the progress of the corridor excavation. Extremely important information collected at this stage includes, but is not limited to, the web time, the progress made, the amount excavated, and the volume of rock in the face. The following criteria are identified for the excavation process:

- Geological parameters:
  - Longwall length and height,
  - Longitudinal and transverse slope,
  - Dislocation and overgrowth,
  - Volume of rock in the face,
- Technical Parameters:
  - Longwall shearers: type, manufacturer, range of mining height (m), power rating of feed motors (kW), power rating of organ motors (kW), organ,
  - Scraper loaders: height (m), excavation width (m), bottom pressure (MPa), bucket capacity (m^3), loader weight (Mg),
- Economic parameters:
  - Cost of digging one running meter of gallery
  - Cost of consumables
  - Electricity or other fuel consumption.

2. Longwall reinforcement – coal mining using the longwall system requires the longwall (reinforcement) being equipped with a mechanized shearer or plow set. The machinery and equipment comprising a mechanized longwall complex (shearer or plow) generate a significant amount of information. The following criteria are identified in the wall reinforcement process:
   - Geological parameters:
     - Longwall length and height,
     - Longitudinal and transverse slope,
     - Dislocation and overgrowth,
   - Technical Parameters:
     - Coal plow: type, manufacturer, rated power of motors (kW),
     - Shearer: type, manufacturer, rated power (kW),
     - Powered roof support: manufacturer, spreading height range (m), support capacity (MN), control type, section weight (Mg), supply pressure (MPa),
     - Scraper longwall conveyor: type, manufacturer, rated power (kW),
   - Economic parameters:
     - Wall occupancy (%),
     - Cost of reinforcement.
3. Coal mining – In Polish hard coal mines, mining is conducted using the longwall system, in which we distinguish two main categories – a shearer longwall or a plow longwall. The essence of the process is the proper selection of the mining machine, enabling the realization of daily extraction in specific mining and geological conditions, as well as the remaining machines, such as the conveyor or the casing. The following criteria were identified for the mining process:
   - Geological parameters:
     - Longwall length and height,
     - Longitudinal and transverse slope,
     - Cross-section in the crack,

  - Volume of rock in the face,
  - Excavation type,
  - Dislocation and overgrowth,
- Technical parameters (for shearer longwalls):
  - Longwall shearers: type, manufacturer, range of mining height (m), power rating of feed motors (kW), power rating of organ motors (kW), organ,
  - Powered shearer roof support: manufacturer, spreading height range (m), support capacity (MN), control type, section weight (Mg), supply pressure (MPa),
  - Hydraulic units: capacity (dm^3/min), nominal pressure (MPa), supply voltage (kV), total power (kW), unit weight (Mg),
  - Shearer longwall conveyors: chute profile (mm), chute width (mm), conveyor length (m), capacity (Mg/h), power of main drive (kW), power of auxiliary drive (kW), type of discharge (angle, side, face),
- Technical parameters (for plow longwalls):
  - Coal plows: type, manufacturer, range of mining height (m), power rating of feed engines (kW), web (mm),
  - Longwall plow conveyor: chute profile (mm), chute width (mm), conveyor pitch (m), conveyor length (m), chain speed (m/s), capacity (Mg/h), main drive power (kW), auxiliary drive power (kW),
  - Powered plow roof support: manufacturer, spreading height range (m), support capacity (MN), control type, section weight (Mg), supply pressure (MPa),
- Economic parameters:
  - Failure times,
  - Wall occupancy (%),
  - Actual working time of longwall shearers,
  - Effective working time,
  - Emergency stoppage of machines.

4. Longwall decommissioning – is the reverse process of longwall reinforcement and takes place after coal reserves have been exhausted. A resource is considered to be exhausted when the face of the wall reaches the boundary of that wall and all machinery and equipment built in the wall have been dismantled. The following criteria were identified for the decommissioning process:
- Geological parameters:
  - Longwall length and height,
  - Longitudinal and transverse slope,
- Technical Parameters:
  - Mine locomotives: type, drive type, power (kW), speed (m/s),
  - Main and branch haulage conveyors: type, type of haulage, belt speed (m/s), conveyor length (m), average inclination angle, drive power (kW),
- Economic parameters:
  - Longwall decommissioning time,
  - Decommissioning cost.

5. Horizontal and vertical transport is the key logistics process in a mine, linking the extraction of usable minerals at the faces with sorting at the processing plant. Its purpose is also to deliver the necessary materials, machinery and equipment to the face, including the transportation of people. The process of vertical transport i.e. the haulage of excavated material to the surface through shafts is carried out in skips. Mine shaft hoists are equipped with vertical-rope transport systems (e.g. a hoisting machine, support and compensating ropes, extraction vessels). The excavated material is transported by conveyors to the shaft expansion tanks, where it is loaded into a skip vessel and transported to the surface, where it is unloaded in the shaft top and collected by the processing plant. The following criteria were identified for the decommissioning process:
   - Geological parameters:
     - Longwall length and height,
     - Longitudinal and transverse slope,
     - Dislocation and overgrowth,
     - Excavation type,
   - Technical parameters (for bottom workings):
     - Bottom/scraper bridge conveyors: chute profile (mm), chute width (mm), conveyor pitch (m), conveyor length (m), capacity (Mg/h), drive power (kW),
     - Scraper loaders: height (m), excavation width (m), bottom pressure (MPa), bucket capacity (m^3), loader weight (Mg),
     - Bottom crushers: capacity (Mg/h), stroke of lifting cylinder (mm), drive power (kW), width of crushing drum (mm), weight of crusher (Mg),
   - Technical parameters (for capital workings classified as fixed assets):
     - Mine locomotives: type, drive type, power (kW), speed (m/s),
     - Main and branch haulage conveyors: type, type of haulage, belt speed (m/s), conveyor length (m), average inclination angle, drive power (kW),
   - Technical parameters (for vertical transport):
     - Mining shaft hoists intended for hauling of excavated material on surfaces/for carrying people: type, engine power (kW), transport speed of excavated material/people (m/s), weight of excavated material in a skip (Mg), device capacity (Mg/h),
   - Economic parameters:
     - Effective shaft working time,
     - Driving efficiency in the shaft,
     - Ventilation shaft maintenance costs,
     - Cost of ventilation, drainage and compressed air,
     - Cost of shaft heating,
     - Cost of central air conditioning,
     - Operating time of the device loaded at 50–100% of the nominal current load,
     - Maintenance operations (number of replaced rollers, belt joints, number of linear meters of belt replaced),

- Cost of crew and materials,
- Indicator of device drive load,
- Indicator of device power consumption.

The entry of records of parameters pertaining to mining and geological conditions at every stage of the mining process for longwall workings will make it possible to identify the reasons for failure or varied performance of machinery. Keeping comprehensive records of the technical parameters of machines and their work history is an important part of proper asset management. This provides a basis for the proper selection of machines for specific conditions of a given longwall (section, region). In turn, recording the functioning of the elements of the mine logistics system is an important element of the continuity of the production process.

Storage, protection and monitoring of verified machine data on operation, repairs, maintenance and servicing as well as failures enables correct operation, quantitative and qualitative analysis of phenomena, thus eliminating the frequency of failures. There is also the added value of being able to indicate the places which are most vulnerable to these risks. Figure 4 shows a proposed process for sharing and validating data in a mining company on a Blockchain network.

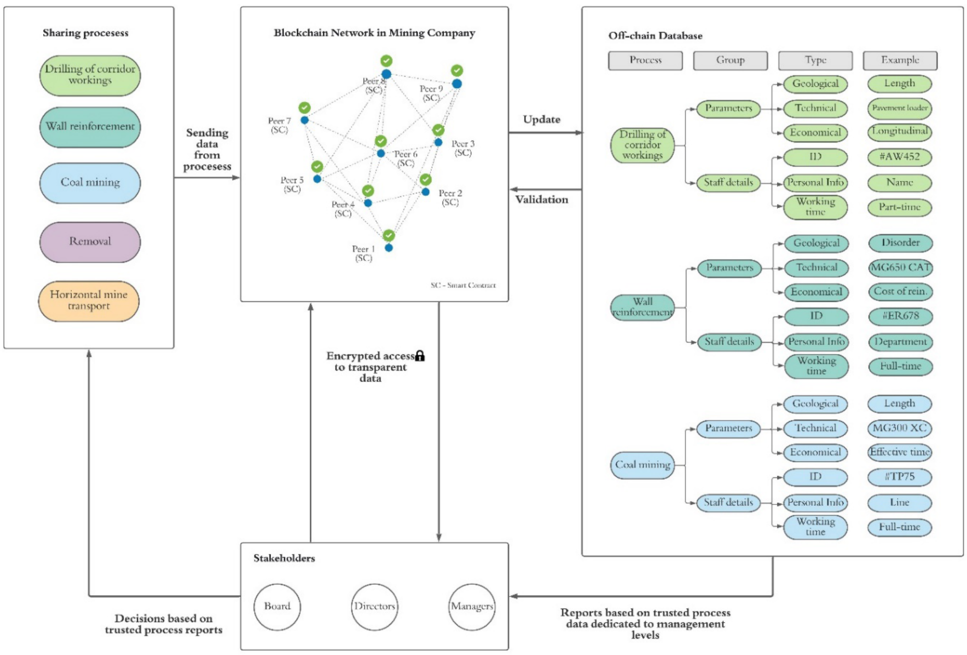

Fig. 4. Schematic of the data sharing and validation process in a mining company using Blockchain technology

Rys. 4. Schemat procesu udostępniania i walidacji danych w firmie wydobywczej wykorzystującej technologię Blockchain

The reliability of data can realistically affect the value of companies that provide data (exploration companies) as well as those which use that data for their internal purposes (mining companies). Safeguards at the level of individual processes, treated as transactions in the chain, can exclude the interference of third parties who may affect the changes of production parameters while pursuing their private interests that are not beneficial to the objectives of creating company value. The recording of data in a Blockchain network is therefore intended to be validation in nature, confirming that the data is consistent with reality.

Being a system based on decentralization, Blockchain allows data verification by multiple users. In the context of providing reliable data, this process is crucial and necessary for the relative objectivity of the data being analyzed.

2.2. Supply chain monitoring

Supply chain management is a fundamental process in business strategy that defines the development parameters and steps that accompany the process of planning, manufacturing, distributing, and selling goods. For minerals, this cycle begins with the processes of exploration, extraction, and sale to the target customer (Shan et al. 2014). Each process is characterized by distinct parameters that are passed on to the next stage of the delivery process. The chain parameters for coking coal are summarized in Table 3. In contrast, a proposal of a supply chain monitoring system for this raw material, based on Blockchain technology, is presented in Figure 5. It outlines the basic capabilities for collecting reliable data at each of the stages of the chain listed in Table 3, ensuring that appropriate responses can be made based on verified information.

Table 3. Basic raw material parameters in terms of supply chain processes

Tabela 3. Podstawowe parametry surowców z punktu widzenia procesów łańcucha dostaw

	Exploration process	Extraction process	Sales process
Technical parameters	Geological documentation/ Coal samples from boreholes/Map of deposit quality	Deposit sampling: fault sampling, drift sampling in a given seam and borehole sampling	Commercial coal quality testing, monitoring the claims process
Economic purpose	The rationale for implementing the exploration project Correct selection of the operating system	Correct selection of process machinery and reasonable mining costs	Profitability of the sales process/margin Preventing unsubstantiated complaints

In the exploration process, information on the accessibility of the deposit and physical and mechanical parameters of the rocks surrounding the projected coal seam are needed in

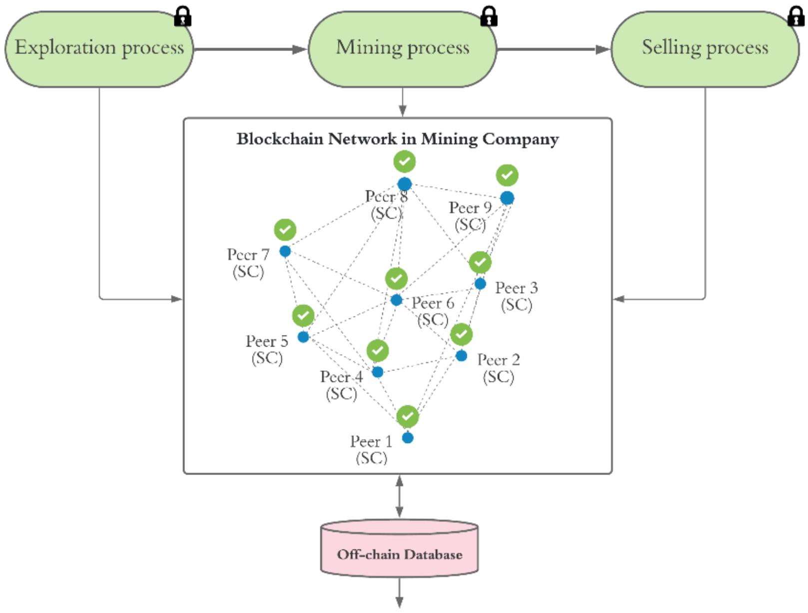

Fig. 5. Schematic of the supply chain process monitoring for coking coal

Rys. 5. Schemat monitorowania procesu łańcucha dostaw węgla koksowego

order to initiate and carry out correct, economically efficient and safe exploitation (Classification of roof rock according to GIG – Classification by A. Biliński). These are:

- layer type (roof/floor),
- layer thickness (m),
- compressive strength Rc (MPa),
- tensile strength Rr (MPa),
- compactness index f (–),
- compactness category,
- ceiling type,
- floor type,
- slakeability index r (–),
- RQD (%).

In addition, it is necessary to have information about the parameters of the deposit, obtained from the drilled test holes. These include: structural parameters of the deposit (tectonics, sedimentary disturbance), qualitative parameters of the deposit (depth, thickness of the deposit with overgrowth, overgrowth, angle of inclination). Natural hazards (methane hazards, coal dust explosion hazards, gas and rock bursts, boulder hazards, water hazards, climate hazards, coal's propensity to spontaneous combustion) will also be important.

In the phase of the output (raw material) extraction process, important information will include geometric parameters of the longwall such as:

- longwall location,
- longwall length,
- rundown time,
- transverse and longitudinal slope ratio,
- types of machinery and equipment,
- length of haulage and transport,
- the time it takes for workers to get to or from the wall.

The preparation of comprehensive data at the initial stage of exploration allows for the appropriate selection of surface protection categories, characteristics of the coal seam, the type of roof and floor rock located in its immediate vicinity, the shape of the selected part of the deposit, the concentration of extraction, minimization of deposit losses and the use of modern mechanization.

The raw material transported to the processing plant undergoes further technological processes (mechanical classification, screening, crushing, enrichment, dewatering, dedusting, desilting, washing out, drying).

An important element in the product supply chain is the production of coal with appropriate parameters that determine its saleability, i.e. commercial coking coal. These are:

- type of coal according to Polish Standards,
- Ash content Ad (%),
- moisture content Wtr (%),
- Sulfur content Std (%),
- volatile content (Vdaf %),
- sinterability (RI),
- slow smoking (SI),
- expansion joint (b %),
- Post-reaction strength (CSR %),
- Reactivity of coke with CO_2 (CRI %).

This information is necessary for the proper preparation of the coke production process, in which only selected grades of coal can be used, for example coking coals that are properly blended (preparation of the so-called coal mix).

Data collection and analysis may not only concern the main extraction processes or those related to raw material parameters. It may include a number of processes that support the main technological process, related to, for example, environmental protection, recovery of by-products from the main technological process, quality control, complaints, inventory management.

Based on the above data, a flowchart of the supply chain monitoring process for coking coal was prepared including traceability of information and parameters from verified and secured sources for stakeholders. It is shown in Figure 6.

The implementation of Blockchain technology in the supply chain for coking coal may prove to be important in terms of tracking information about the origin of the raw material and transmitting key parameters with the ability to view them in real time. A similar ap-

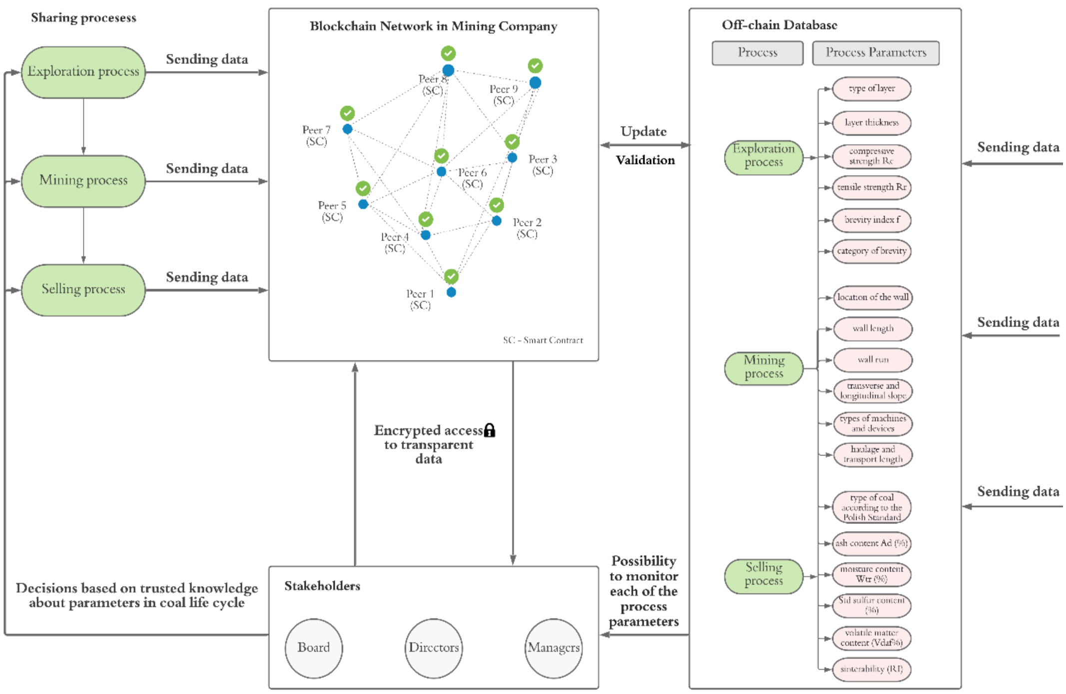

Fig. 6. Life cycle based process monitoring diagram for coking coal supply chain

Rys. 6. Schemat monitorowania procesu w oparciu o cykl życia łańcucha dostaw węgla koksowego

proach is used when mining diamonds for jewelry purposes. Choi's research confirms the applicability of technology in the authentication and certification of diamonds throughout the product life cycle (Choi 2019).

It is therefore possible to apply such monitoring to the extraction of other minerals that are used in industry. Data flow monitoring for commodities such as coal, copper and silver can positively impact their market value by increasing confidence in the values held from exploration areas. An additional value of this solution is the possibility to verify the origin of a particular batch of raw material. This can help in purchasing decisions for a particular raw material from areas with known geological parameters and conditions. Additionally, the final purchase and sales transactions, through the use of Blockchain technology, can take place without intermediaries, which may involve a reduction in brokerage costs.

There are already several companies in the industrial sector that have successfully implemented decentralized systems projects for industrial process improvement (Dutta et al. 2020). These companies are implementing supply chain improvement processes to a large extent. In October 2019, Google published a paper on improving the efficiency of mineral use in the supply chain by using Blockchain-based commodity monitoring. The main objective is to improve the transparency of operations and raise awareness about the responsible use of minerals in industrial processes that are carried out by the supply chains of companies and national governments.

2.3. Implementation possibilities – summary of research results

Analyzing the knowledge gathered so far, regarding the implementation of Blockchain technology in various industries, two main directions for its implementation into the resource industry are proposed:

- The implementation capabilities are primarily in the area of raw material data security. For the considered case of coking coal, characteristic parameters describing the processes of raw material extraction were formulated. This representation of data enables its decentralization and possibility of aggregation in various configurations, based on verified and fully secured data. The aforementioned protection makes the value of this kind of data increase. Increased confidence in data translates directly into decision-making processes related to the management of mining processes, such as seam excavation, longwall development or decommissioning, and transportation processes. Each of the listed processes requires continuous monitoring and reporting. Daily reports on the production of longwall systems and their failure rates, information on the occupancy of longwalls, downtimes, both planned and unplanned, require reliable data that reflects reality as closely as possible. The data will also help identify the causes of machine failures or unstable performance. Hence, the quality of the data and its appropriate protection against the interference of third parties is such an important issue.
- The second area analyzed is supply chain monitoring for coking coal. The analysis isolated a basic chain based on three pillars: exploration, extraction and sales. Each of the listed pillars has a number of parameters that describe the process. The use of Blockchain technology in this area can be based on the tracking of coal parameters over its life cycle. The characteristics of the analyzed technology provide a complete record of events, transactions, and carbon parameter flows. In particular, the tracking of parameters will allow for a more accurate selection of the coal mixture, which is prepared from specially selected types of coal. Processes supporting the main technological process, related to environmental protection, quality control or inventory management, will also benefit from parameter monitoring. Decisions based on proven parameters make much more sense from the technological and economic point of view.

Blockchain technology has the potential to play a very important role in restoring trust in data from the raw material industry. In the Polish mining reality, each piece of additional information about the technological process is an added value to the whole value chain of the company. Companies in the raw materials industry in Poland have to meet new environmental and legal requirements, building their reputation on the credibility and transparency of their operations. Blockchain can be one of the main tools to help build a long-term sustainability strategy, while ensuring that the data on which they base their plans is fully reliable and secure. Moving towards reasonable carbon management, Blockchain provides a tool to fully control the assets owned, processes executed and products sold.

Conclusions

Summarizing the considerations on the directions of use of the Blockchain technology in the raw material industry, it is worth pointing out two main areas where the mentioned technology can be implemented. The first is in the area of data security, where technology that is advanced in terms of cryptography and security can be an alternative to the safeguards used to date. This is important as mining moves toward Industry 4.0, which relies heavily on modern machinery sending exponentially growing amounts of data. Therefore, by ensuring the security of data flow between internal users, one can expect that enterprises will be interested in developing technology that will enable data transfer in a fully secure and transparent manner. A major advantage of this solution is its decentralized architecture, which naturally allows information to be stored in several locations. This is a necessary requirement for today's cybersecurity standards governing data security. The cost of investment in computing machines may be a barrier to the implementation of such a solution. Depending on the variant adopted, these machines can be located within an in-house server room or the calculations can be outsourced. By design, option two may not be viable given the high memory consumption of the header extraction process.

The second direction is the implementation of Blockchain technology in monitoring supply chain processes and tracking raw material parameters throughout their life cycle. Work on the feasibility of the studied architecture has been ongoing for more than a decade. A breakthrough moment came in 2016 when Everledger announced success in its work on a technology that enables virtual certification of diamonds over their life cycle. This process made it possible to improve the reliability of the information regarding the origin of the diamond and to establish, through certification, that it did not come from crime or other illegal sources. Therefore, there is potential for the implementation for other minerals, the extraction of which may be strategic from a stakeholder perspective. Reliability of the origin and parameters of raw materials is a competitive advantage for mining and exploration companies. Relying on verified information, these companies engage in a long-term process which, from the point of view of the environment and local communities, is very invasive, and from the point of view of investment, is risky and expensive. The area related to the reliability of information provided and the security of its transfer and analysis is one of the most important from a strategic point of view. This is because it concerns the accuracy of forecasts related to the resources of deposits, their location and the most important parameters. The use of Blockchain technology in this area can result in increased trust in the relationship between the deposit information provider, the mining company, and the target customer (in the form of a power plant or other industrial facility). Greater awareness of the origin and real parameters of the deposit may result in better investment decisions regarding the purchase of new machinery or launching production on another longwall. In addition, better knowledge of a given raw material batch can result in a more favorable selection of parameters in the raw material processing, better adaptation and utilization of the existing machine park.

The chain of dependence begins with reliable information, which, if secured in the right way, can presently determine the value of a company. Building platforms that allow one to view processes in real time is becoming the norm in today's world. While protected in a modern way, these platforms provide an opportunity to use modern technology to address current issues of credibility and trust in information. The demand for information grows as the years go by, so new directions for the use of Blockchain technology in the mining industry may emerge. Subsequent publications testify to the interest in this technology not only in the context of cryptocurrencies or making money from Bitcoin investments. They are primarily concerned with the ability to bridge the trust gap that has appeared naturally in the virtual world.

In conclusion, the topic of Blockchain technology in mining should be developed in the context of work on systems that, while being highly secure and trusted, can monitor and trace the origin and parameters of raw materials in their life cycle. This knowledge will optimize mining, production or sales processes and enable mining to realistically adapt to the era of a highly modernized industry, reducing the impact of misinformation and lack of trust in processed data.

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DIRECTIONS FOR USING THE BLOCKCHAIN TECHNOLOGY IN THE RAW MATERIALS INDUSTRY

Keywords

raw materials innovation, blockchain, modern technologies, mining

Abstract

Modern technologies have been revolutionizing industries for years, providing competitive advantages to companies. As a technology based on decentralization, Blockchain becomes a tool to support and secure processes and transactions in industries such as mining and power engineering. It also supports supply chain processes, which are particularly important in today's mining business. The use of advanced cryptography methods results in increased cyber security in entities that implement such solutions. The use of Blockchain technology carries a strong message, both to competitors and customers, about intensifying work on authentication and process traceability. This publication focuses on defining the trust gap problem in the mining industry and on examples of the use of technology in data traceability processes. The mining industry is beginning to use technologies which had been previously available only in the theoretical realm. The ongoing development towards a smart industry entails a number of studies and expert assessments, aimed to integrate knowledge from the mining and IT areas. The combination of these research areas leads to an increase in the value of both the companies implementing modern technologies and traditional companies that implement such applications in their value chain. Based on the analyzed articles, two main areas of consideration in the context of the extractive industry were distinguished: systems that track and secure the flow of data in specific mining processes and systems that monitor and secure information on processes which support the raw materials supply chain.

KIERUNKI WYKORZYSTANIA TECHNOLOGII BLOCKCHAIN W PRZEMYŚLE SUROWCOWYM

Słowa kluczowe

innowacje surowcowe, blockchain, nowoczesne technologie, wydobycie

Streszczenie

Nowoczesne technologie od lat rewolucjonizują przemysł i stanowią o przewadze konkurencyjnej przedsiębiorstw. Blockchain jako technologia oparta na decentralizacji staje się narzędziem wspomagającym oraz zabezpieczającym procesy i transakcje w takich gałęziach przemysłu jak górnictwo oraz energetyka. Wspomaga również procesy związane z łańcuchami dostaw, szczególnie ważnymi w dzisiejszym biznesie wydobywczym. Wykorzystanie metod zaawansowanej kryptografii skutkuje zwiększeniem cyberbezpieczeństwa podmiotów, które takie rozwiązania wdrażają. Zastosowanie technologii Blockchain wiąże się z mocnym przekazem, zarówno dla konkurencji jak i klientów, dotyczącym intensyfikacji prac nad autentykacją oraz identyfikowalnością procesów.

W niniejszej publikacji skupiono się na zdefiniowaniu problemu luki zaufania w przemyśle górniczym oraz przykładach wykorzystania technologii w procesach śledzenia pochodzenia danych. Branża wydobywcza zaczyna wykorzystywać technologie dostępne do tej pory tylko w obszarze teoretycznym. Bieżący rozwój w kierunku przemysłu inteligentnego niesie za sobą szereg badań i ekspertyz, które mają na celu integrację wiedzy z obszarów górnictwa oraz informatyzacji. Połączenie wspomnianych obszarów badawczych prowadzi do wzrostu wartości przedsiębiorstw zarówno wdrażających nowoczesne technologie jak i firm tradycyjnych, które takie zastosowania implementują do swojego łańcucha wartości. Bazując na analizowanych artykułach wyróżniono dwa główne obszary rozważań w kontekście branży wydobywczej: systemy śledzące oraz zabezpieczające przepływ danych w określonych procesach górniczych oraz systemy monitorujące oraz zabezpieczające informacje dotyczące procesów wspierających łańcuch dostaw.