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Tracking mining company electric vehicles for sustainable development optimization using Distributed Ledger Technologies

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Abstract

It is established that based on the industrial revolutions towards Industry 5.0, the population of the Earth and its well-being are increasing. To preserve and improve living conditions the development in all spheres of life is by the paradigm of sustainable development. Through the prism of the mining industry, one step could be the introduction of circular economy measures for digitized tracking of materials, repairs, consumed electricity, safety, and finances. Implementing of electric cars is an option to achieve this goal through automation, manageability, and data traceability via Industry 4.0 technologies. Such are blockchain technologies, IoT, V2V, and others. For this purpose, the appropriate types of power supplies for electric vehicles for the mining sector have been identified and information flows have been defined. They are quantity of material, consumed electricity, state of the fleet, charging of batteries and operation of charging stations, and finances. For their implementation, Hyperledger Fabric was chosen as a suitable DLT platform ([1], [2]). Based on Hyperledger Fabric, a conceptual model for tracking material quantities as a step of the circular economy is proposed. A method of communication is shown in the presence of two channels - material and repairs for an electric car.

Keywords

distributed ledger technology; blockchain; electric vehicles; circular economy; Sustainable Development

RESEARCH ARTICLE

Tracking mining company electric vehicles for sustainable development optimization using distributed ledger technologies

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Abstract

In the article, it is established that based on the industrial revolutions towards Industry 5.0, the population of the Earth and its well-being are increasing. To preserve and improve living conditions, development in all spheres of life is done using the paradigm of sustainable development. Through the prism of the mining industry, one step could be the introduction of circular economy measures for digitized tracking of materials, repairs, consumed electricity, safety, and finances. Implementing electric cars is an option to achieve this goal through automation, manageability, and data traceability via Industry 4.0 technologies such as blockchain technologies, IoT, V2V, and others. For this purpose, the appropriate types of power supplies for electric vehicles for the mining sector have been identified, and information flows have been defined. They are the quantity of material, consumed electricity, the state of the fleet, charging of batteries, operation of charging stations, and finances. For their implementation, Hyperledger Fabric was chosen as a suitable Distributed Ledger Technology (DLT) platform. Based on Hyperledger Fabric, a conceptual model for tracking material quantities as a step of the circular economy is proposed. A method of communication is shown in the presence of two channels − material and repairs for an electric car.

Keywords: distributed ledger technology, blockchain, electric vehicles, circular economy, sustainable development

1. Introduction

Advances in medicine and increased agricultural production are cited as the main reasons for the growth of the world's population, which is associated with an increase in the consumption of all kinds of resources. Their provision is accompanied by the development of new agricultural areas and the development of industry, or the so-called industrial revolution. The term was coined by Arnold Toynbee to assess the economic development of Great Britain between 1760 and 1840 [3]. Economic development continues at a rapid pace simultaneously with the growth of the Earth's population, as in 1804 it was 1 billion, 1959 − 3 billion, 1974 − 4 billion, and at the beginning of the 21st century it reached 6 billion people, etc. [4].

These processes are aided by the transfer of goods and the search for markets, leading to the development of infrastructure and transport. Humanity is faced with the question of ensuring a good standard of living with its continuous growth. There is talk of the paradigm of sustainable development, which is related to increasing the parameters in one area in a way that does not harm another. Various measures have been introduced to achieve this. One is the realization of a circular economy, i.e., the seizure of raw materials, their processing, consumption, and re-processing of original raw materials [5]. A step towards achieving this goal is tracking material flows from excavating, particularly from the mining sector, with sustainable energy consumption.

According to the Green Deal, carbon emissions must be reduced to achieve sustainable development, most often through a circular economy. These measures cover all sectors for the entire production and life cycle of the products [5]. This means automated and connected multimodal mobility, smart traffic management systems, digitalization, and sustainable mobility, which can be achieved by implementing distributed ledger technology [6]. For the conditions of Bulgaria, this technology has not

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been introduced, but private automated control systems are used.

1.1. *Defining the problem*

The automated and connected multimodal can be achieved by deploying electric cars with high autonomy, subsequently sharing the data via DLT, and analyzing it with the big data method for higher efficiency than in the moment [1,2].

1.2. *Industrial revolution*

Originating in Britain, the transition from an agrarian to an industrial society marked the beginning of the first industrial revolution. The production of steam engines and technology remained concentrated on the island due to a ban on their export. At the same time, roads and factories are being built. Despite the policy of the English government, at the beginning of the 19th century, all of Europe began to be industrialized, increasing the transfer of products and raw materials through steam engines and new transport lines.

The discovery of electricity marked the beginning of the Second Industrial Revolution. Technology lines driven by electricity are emerging. Communication through telephone, radio, and electric transport is enhanced, leading to urbanization and an increased share of GDP per unit of population. The first electric vehicle appeared in 1851 (IFP, 2020). Due to the increased cost of maintenance, since 1920, electric cars have been replaced by diesel cars. Since about 1935, electric vehicles are no longer part of mass transportation, but rail vehicles remain in motion.

Communications have accelerated during the third industrial revolution with the transition from analog to digital technology and the advent of cellular communication technologies. During this period, electric transport existed mainly in cities in the form of trams and rarely in underground mines, mainly as rubber conveyor belts. In many industrial workshops and warehouses, battery-powered electric trucks are used to transport goods.

During the fourth industrial revolution, the development of science and technology is in the direction of biology, robotics, 3D printing, artificial intelligence, the Internet of Things, etc. It is digitization that creates the need to return humanity to electric transportation. Several factors make it necessary.

First, there are the requirements of the Paris Agreement to reduce carbon emissions [7,8]. According to the decisions from Paris, one of the measures envisages the replacement of vehicles from internal combustion engines (ICE) with electric ones in the context of increasing energy efficiency [9,10]. Naturally, the method of production of the consumed electricity matters, preferring it to be from renewable sources or nuclear. There are already examples of working vehicles powered by solar panels, which is in line with the sustainable development paradigm by improving social, economic, and environmental criteria [11].

Second, the advantages of electro-mobiles, especially in the conditions of underground mining, such as mobility, low carbon emissions, high efficiency and passability, reduced cost, and others, are indisputable [12]. They "produce" a reduced amount of particulate matter and thus improve the local ecosystem if they use a renewable source of energy and recycling technology for batteries. For example, in Table 1, the parameters of the main types of vehicles for LCA are applied [13].

From an environmental point of view, it is not only the generation of harmful emissions during the operation of the vehicle that is important but for the entire life cycle. In a CO_2 gas study, Electric mobile vehicles with batteries (BEVs) are proven to have

Table 1. Parameters of the main types of vehicles.

Kind	Internal combustion engines – ICEV	Battery electric vehicle – BEV	Hybrid vehicle HEV	Fuel cell vehicle
Infrastructure	Plentiful	Medium	Very limited	Very limited
Power	High power	Lower than ICE, and depends upon the battery pack	Intermediate	High power, depends upon fuel cell stack size
Pollution	HC, CO, CO_2, NO_x, and PM	Zero tailpipe emission, depends upon the source of electricity generation	Lower but still produces emissions	Zero tailpipe emission, depends upon the source of hydrogen generation
Efficiency	20–35%	60–70%	25–43%	55–66%
Cost	Lower	Higher vehicle	Higher vehicle	Higher vehicle
Maintenance cost	Lower maintenance cost	Higher maintenance cost	Higher maintenance cost	Higher maintenance cost
Fuel cost per km	$0.081–0.13	$ 0.0315–0.0541	$0.079	$ 0.080–0.18

lower carbon emissions for life cycle assessment (LCA) compared to Internal Combustion Engine Vehicles (ICEV) [10]. For example, BEV 39t CO_2, HEV 47t CO_2, and ICEV 55t CO_2 [14]. Efficiency is 85–90% at high and medium voltage, and at low – 95%, and ICEV– 40%. Quantities increase as vehicle mass increases. The results are important because they cover a period from the extraction of the raw materials, their processing, the production of the product, the use, and the end of the car. According to the scientists, the use phase is the most impactful of all stages, followed by raw material extraction and battery production. Emphasis is placed on the possibility of recycling the latter by investing in photovoltaic panels. This assessment should be related to the classification of all types of raw materials and tracked from the stage of extraction through transport to input and recycling [15]. The analyses did not omit to determine the harmful carbon emissions during transport and disposal of the electric mobile means at the end of the life cycle according to the geographical features and the energy mix for each country.

The carbon footprint generated by LCA in countries producing electricity from coal and oil was found to be, unfortunately, high. In contrast, leaders in clean and renewable energies are France, Norway, and Sweden; therefore, their electric cars are also ecologically cleaner [9,10,16].

Concerning each country's electricity mix, it is found that consumers can generate profits by offering renewable energy subsidies for BEVs. The research methodology developed is valid for city vehicles but can also be applied to mine electric transport [9]. A shortcoming of the research provided is the comparison between BEV and ICEV only, but given the findings, it is clear that regulatory and policy efforts should be made to popularize these tools in the mining industry as well.

It is necessary to implement various measures to motivate not only people but also companies to use electric cars. Increasing the motivation and ability to analyze the LCA of raw materials and other parameters are enhanced by using digitalized tracking methods through Blockchain [12].

Third, with the development of technical means, the controllability of electric cars can be increased through the Internet of Things and Blockchain (one method of the DLTs – Distributed Ledger Technologies is a ledger for replicating identical data to all participating nodes [1,2]).

The implementation of these technologies in BEV is easier compared to those with the ICEV. In addition, electric cars allow for a higher level of automation, which supports compliance with the conditions for sustainable development, meaning that development in one area should not negatively affect another area. In the considered context, this transport must have a positive economic, social, and environmental effect [17–19]. This is directly related to reaching the next level of industrialization, namely Industry 5.0, which is human-centered (Fig. 1).

1.3. The new information technologies and the mining industry

Despite the rediscovery of the advantages of electric transport in recent years, it has been subject to automation in the mining industry since the last century. There is a clear trend towards an increase in the level of automation, which is impossible with the ICE. Proof of this is the implementation of the first underground motor in the Blumenthal mine (Germany) in 1967, classified as the first level of automation, i.e., the control selects an appropriate speed without the driver's involvement. With the introduction of remote control of underground transport in the USA, a second level of automation is reached, with tracking through dispatch cameras and driving requiring human intervention. The third level of automation requires no human intervention and was implemented in the 1990s with coal mine loading and hauling machines operated by surface dispatchers [20]. With them, the driver turns on after presetting the means of automatic control. Level 5 human absence already exists in Texas for ground transportation [21,22].

In support of the implementation of electric cars with a high level of automation are the requirements for reduced carbon emissions, increased

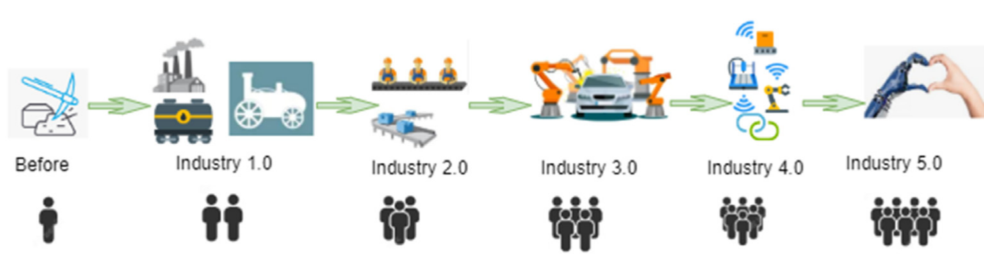

Fig. 1. From beginning to Industry 5.0.

safety and comfort of workers according to the concept of sustainable development. This challenge can be achieved through the following steps [23]:

- Changing current mining practices and techniques;
- Optimizing efficiency under the Paris Agreement;
- Construction of smart mines and management through artificial intelligence;
- Introduction of data sharing through Blockchain;
- Enhancing mine safety through unmanned technologies and training;
- Tracking the material quantities and the level of accidents to optimize the process.

It is the tracking of material quantities that is the basis for realizing a circular economy as one of the means to achieve sustainable development [15,24]. The latter statement supports efforts to implement not just electric cars in the mining industry but also their management through the means of Industry 4.0. In retrospect, it can be seen that their automation in industry or an urban environment is feasible through modern technologies such as IoT, BD, Neural networks, and DLT [25,26]. It enables data analysis, management, and sharing in order to reach the last level of autonomy, build a SMART network, and achieve safety in management and charging [27–29].

In this case, it is necessary to manage data flows for the amount of materials, energy, parts, and others. A problem in enterprises working with confidential data is modifying and digitizing information flows by implementing DLT. One of these sectors is mining, although there are several very modern mines in Bulgaria. In them, data on the state of equipment and technological processes are transmitted digitally for analysis within the company's structure. DLT is possible based on a permissioned platform. With regulatory requirements for publicizing on government sites, and the quantities of mined seized (often coal), the development of a hybrid system is required.

Existing non-DLT-based systems are owned by the respective mining companies. In this way, the integrity of the data stored in the arrays of the companies and those stored in the respondent organizations cannot be guaranteed. In this way, data can be easily manipulated without this action being controlled and noticed by the participants in the data exchange. Using proprietary, non-shared information channels puts data at risk in the event of technical problems, natural disasters, or other events beyond the participants' control.

There is currently a gap in the sector due to an assessment of the low maturity of DLT implementation [30]. The application of blockchain for the mining industry, not only for driving electric vehicles but also for tracking raw materials, is low. Only IBM is working on the issue of implementing BC for transport management in their [31]. Proof of the applicability of DLT is the achievement of security in energy management and charging of electric vehicles, which is essential for increasing the efficiency of mining processes [29,32]. In addition, a tracking system for cobalt from mines that have not been digitized in Africa is to be built [31]. Another project on the MineHub platform is to manage ore from GoldCorp's Penasquito Mine in Mexico to the market. What they have in common is that they are based on the principle of creating an information flow among small remote companies and large centers for proof of origin [31]. The latter cannot be realized without digitized management and tracking of means of transport, which is another proof of the need for the Distributed Ledger in electric transport.

Therefore, the collection, sharing and storage of data are steps towards their analysis. State-of-the-art research shows that the use of blockchain serves big data applications by complementing them, enhancing security, analysis capabilities, integrity, and accuracy of results in the Smart City, Smart Healthcare, Smart Transportation, and Smart Grid sectors, and others [33]. This is strongly true for the mining industry, where heterogeneous, structured, or unstructured data, classified as "big data" are collected [34]. Therefore, harmonizing and complementing the work of technologies is a challenge for real competitiveness not only in industry but in the whole society in order to raise the standard of living and meet the criteria of sustainable development.

Therefore, the aim of the article is to propose conceptual models for the use case of main directions for the implementation of a DLT platform for the management of electric vehicles in mining enterprises. This data will be used for further analysis to improve performance.

1.4. Research methodology

To achieve the set task, the opportunities and obstacles in the implementation of blockchain technologies in the management of electric vehicles in mining enterprises have been analyzed and the various systems for their management have been described. Remote management of funds and their inclusion in a SMART network is possible using several technologies. Distributed ledger technologies

(DLT), known as Blockchain, serve to share secure and unmodified data among peers without the involvement of a third party. Data is recorded/transmitted by hashing, i.e., creating a unique key or digital fingerprint for each file that protects the sender's authenticity. DLTs are most often built on the basis of a blockchain, i.e., on the principle of a chain of blocks with identical, growing with new entries and encrypted information. Participants can be mining companies, transport and repair companies, regulatory bodies, banks, and others. In our case of managing the fleet of a mine, the shared Blockchain data is sent in addition to the listed authorities and to Big Data, which will use it for subsequent analysis to improve efficiency, for example by changing its routing.

Given the possibilities of traceable data sharing, DLT has been chosen to exchange data obtained from the built IoT management network. The Internet of Things (IoT) is a network of objects identified by unique identifiers (UIDs) that can transfer data in real time without human intervention. Thus, a type of products such as pharmaceutical, agricultural, construction, or mining can take advantage of the data obtained and analyze it, optimize processes, increase the safety of machines and workers, lower levels of harmful emissions, healthy environment [35]. This applies to a large extent to hazardous industries such as mining, chemicals, and pharmaceuticals [23,36].

2. Materials and methods

The implementation of IoT depends on various factors such as the level of automation, availability of sensors and wireless data transmission, storage and analysis technologies, etc. The data measured by the sensors must be stored in a database from which the information required for each communication channel can be extracted and sent to the relevant actor. Sharing this data via DLT requires defining the main directions specific to electric mining transport and determining basic information flows.

2.1. DLT's place to connect EVs to a grid

2.1.1. Benefits of networking

Creating a remote control network is not only about convenience but also about increasing security, efficiency, and, hence, economic indicators. We are currently working on new capabilities for EV drivers in urban environments that provide them with Blockchain communication with other EVs defined in the following information flows: toll payment, green wave routing, congestion presence, road condition, tokenization of harmful emissions, and others. All of them push big companies like IOTA, Corda, and Ethereum to work to create Smart cities [37–39]. Several key benefits can be highlighted for the mining sector, proving that vehicles should be networked:

- Drivers' awareness of the road and traffic conditions, such as active road works, number of loaded or unloaded electric trucks, movement of the stop, and traffic light conditions, which will lead to traffic without unnecessary movements. The sharing of the cited disparate data is done through a peer-to-peer mesh network, such as transmission in the multi-channel DLT platform Hyperledger Fabric [40]. Therefore, it is one of the preferred blockchain platforms;
- Reduction or avoidance of accidents due to the presence of other vehicles, change of road sections in mining workings, and passing workers. This communication has been proven to reduce incidents. The immutable data recorded and transmitted via Hyperledger Fabric will help unambiguously alert the driver of route changes;
- In the presence of fully automated transport, dust and gas hazardous industries such as coal mines will be able to introduce autonomous trucks controlled remotely by professional drivers. DLT is at the heart of increasing security according to various analysts, especially for the mining sector Infosys [30];
- From a microeconomic point of view, the lack of driver staff, availability of energy-saving driving, high reliability, and accident avoidance are important reasons to use autonomous systems, especially for loading [41]. DLT is not an automated process management system but enables logistics analysis and management correction. This applies to vehicle movement and loading to reduce downtime costs and increase security.
- From a macroeconomic point of view, the structural deficits in the current transport system are resolved through automated systems, mainly through the development of the railway network and their use, if necessary, in the mining industry. One of the digital platforms for this is Hyperledger Fabric. Through it, the sending of a warning about a change of route, marking, incident, etc. is immutably proven.
- Changing the regulatory base. The continuous change of the regulatory base requires immediate notification of the participants of the introduction of new rules.

2.1.2. Necessary technologies

The benefits of DLT connectivity are impossible without the signals from the IoT network, which feeds data from sensors, services, or micropayments. In this case, these are signals for passing cars, the presence of an obstacle, adjusting the signal in case of fog, reaching a starting or ending point, changing a route, and others. To implement the described communication, it is necessary that electric underground or above-ground cars have the highest levels of automation according to the criteria of hands (on/off), eyes (on/off), and mind (on/off). It was mentioned that the highest level 5, with no human behind the wheel, is a project of METRO [41]. This company has partnered with Texas Southern University for a pilot program in which an autonomous shuttle will operate on a 1-mile, closed-loop route along TSU's Tiger Walk. Other applications have been made by Peloton Technology [21] and a start-up firm in Menlo Park, California, that is seeking to commercialize V2V (vehicle-to-vehicle communication) technology for heavy trucks [22,40]. V2V communication allows the exchange of traffic data, accidents, road conditions, and routes among cars on the road through a peer-to-peer mesh network. Each element of the path can receive, process, and relay a message.

Accompanying technologies for carrying out freight transport are an autonomous, decentralized AGT/AGV system, radio frequency identification (RFID) technology, V2V, or the presence of a separate transport lane. These vehicles do not provide a seat for the driver. According to the legal regulations, the maximum speed is up to 120 km/h, and in unknown scenarios, such as in mining, this speed cannot be reached [41].

2.1.3. Supplying the fleet

Creating a communication network requires determining the type of data to be measured and shared. Therefore, the vehicle's power supply type must be determined. For the mining industry, the following apply: an ICE with petrol or diesel, HEV or hybrid electric vehicles powered primarily by an internal combustion engine and an electric motor, B.E.V. with rechargeable batteries or Plug-in Hybrid Electric Vehicles – P.H.E.V.s – have an internal combustion engine and an electric motor with a battery [12]. Of the listed, P.H.E.V.s with series architecture are most commonly used in the mining industry due to the high power required, and in some cases, B.E.V.s doing routing for run and load modes. Only the last two types are considered in the proposed conceptual model.

2.2. Advantages and disadvantages of introducing a control system for electric vehicles

Managing the movement of vehicles in mines is just as complex as in cities. Specific in mines is a change of route due to a change of working face, making one-type courses for several cycles. Just like in an urban environment, vehicles need to communicate with each other, protect pedestrians, be functional, have cars charged, etc. What is different here is that these means of transport are used to track the amount of mined and transported material. For this reason, a dispatch system is needed that not only navigates the cars but provides reports on the work done, the amount of transported ore, the state of the fleet, and the charging stations. Despite the advantages of electric cars, the introduction of management and data sharing through Blockchain is associated with the investment of funds [26]. Owners can be motivated by the advantages of the system – immutable, confidential, and crypto-protected data sharing between operating companies without the presence of an intermediary to achieve increased efficiency.

The benefits of implementing DLT are [26,30,33,38,42]:

1. Through blockchain technologies, conventional tasks are performed faster and cheaper due to the elimination of intermediaries. Removes centralized third-party auditors.
2. Supports a shared software network among objects.
3. Non-repudiation and traceability of data flow.
4. Describes different levels of standardization and their importance. High-level functional architecture and participation standards are available for immutability and different roles for blockchain and DLT.
5. The technology is resilient in the event of electrical or internet problems because the information can be used as it is available on other devices.
6. It is possible to grant different rights to individual users – type of data, level of access, and rights to record new data. Thus, the system is automated, errors are reduced.
7. Enables the application of own rules according to the regulatory framework – electronic money, internal system for employee bonuses, and others.
8. Monitoring compliance with safety procedures and sending the relevant questionnaires to employees and companies [43].
9. Blockchain technology makes it easy to trace the flow of data not only among institutions but also

within each institution, proven by the applicability of the system to the banking sector. Such an example is the internal movement of data in large banks and the protection of customer data while complying with regulatory requirements [42].
10. Enables unmanipulated-free transactions in IoT devices.
11. It has high scalability because it allows 1 million writes per second. with sub-second latency.
12. Provides a decentralized, secure, and auditable environment for IoT devices.
13. Improving reliability and stability.
14. Innovation in P2P energy trading and decentralized energy generation by achieving market penetration and commercial viability.

The disadvantages of implementing DLT are:

1. Lack of standards. Currently, there are not enough standards for the technology to function, but they are being developed according to the needs of users. In addition, the regulatory framework is changing and it is expected a new according to EU requirements. Standards are needed for various functionalities in the blockchain.
2. Need to improve consensus mechanisms and improve the protection of private keys. Currently, there are various consensus mechanisms, but work is being done to improve traffic, security, speed, consensus, and other issues. They are different for each platform.
3. Need for prior restructuring at all levels of the organization, changing the responsibilities and obligations of the users of the system. These changes rarely pass without internal resistance from employees, accompanied by short-to medium-term inconveniences, including from a budgetary and organizational point of view (investing in equipment and conducting training, for example).
4. Need to implement digital measuring devices, management systems, software products, and personnel training. This will enable the collection and sharing of digital data as required for the technology to operate. In some industries, including mining, there is a lack of digital measurement of parameters.
5. High consumption of electricity to operate the consensus mechanism validating transactions for some DLT platforms. In some permissioned platforms (e.g. Corda R3), the power consumption is negligible, but in others, proof-of-work requires complex computational procedures (Bitcoin).
6. Lack of participation standard for blockchain immutability.
7. Requires market penetration and commercial viability.
8. There is a lack of a balance between maintaining privacy and accountability.
9. A blockchain implementation system is needed for multi-object accounting.
10. Application development and large-scale testing in sharing economy scenarios.

Based on the pros and cons, it can be summed up that the implementation of DLT for mining transport is a necessity. By analogy with urban transport, it covers various information flows – construction of a network of charging stations, control of the condition of the technical devices (stations, vehicles), and communication among electric vehicles and the road infrastructure. The final step is complex and lacks regulation; an appropriate DLT platform must be selected, and the vehicle control system.

The task is not impossible because a decentralized vehicle charging network has already been implemented, launched by the Mobi group on October 6, 2020. The built network envisages integration of Vehicle to Grid (V2G), Tokenized Carbon Credits (TCC), and Peer-to-peer (P2P) applications [32]. Leading vehicle manufacturing companies have joined the project, with the MOBI EVGI working group chaired by Honda and General Motors (GM), with support from different DLT companies such as Accenture, CPChain, IBM, IOTA Foundation, Pacific Gas & Electric Company (PG&E), Politecnico di Torino and R3 [44]. Volkswagen and Bosch also have contracts for the application of DLT for the management of charging stations [45]. Based on Hyperledger Fabric, Volkswagen has implemented a network to track the origin of materials and parts used to make batteries. In this realization, the necessary settings for Smart City management are defined [38,39,46].

Despite the given examples, currently, DLT systems are not widely used. Therefore, there is a lack of specialists to develop the right design according to the requirements of the specific data flows. The design includes the logical distribution of organizations, key and certificate management systems, infrastructure design, vertical and horizontal system scaling, nodes for reporting behavioral and operational metrics, incident response systems and plans, and estimating the serviceability of the used components. There are production solutions on the market for each of the required components – Influx, Roma, Splunk, Grafana, Seyren, Circonus, OpenSearch Dashboards, and others [47–53]. Given that an open-source framework with an appropriate license is used, training such specialists is a possible task, but costs and time must be foreseen in the business plan for building the system.

From the realized examples of a built smart network for the management of electric vehicles, the free platform Hyperledger Fabric (HLF) stands out as the most suitable in front of Corda and Ethereum [54–56]. For the mining sector, confidential data transmission is required, which excludes public Ethereum. On the other hand, R3 Corda is designed for the banking sector. A cross-platform comparison might look like this [57] shown in Table 2:

Its advantages are the ability to implement a multi-channel structure, a decentralized consensus mechanism, the ability to function when part of the nodes fail and renew the smart contract, and others [58].

Hyperledger Fabric is intended as a foundation for developing applications or solutions with a modular architecture. Hyperledger Fabric allows components, such as consensus and membership services, to be plug-and-play. Its modular and versatile design satisfies a broad range of industry use cases. It offers a unique approach to consensus that enables performance at scale while preserving privacy [54].

The software framework is distributed under the terms of the Apache License 2.0, accessible at [59]. This license permits unrestricted use, including commercial application, and confers a grant of patent rights, which serves to mitigate the risk of patent infringement claims associated with the software. Entities are entitled to modify the source code and develop derivative works from the licensed software, providing significant adaptability for tailoring the software to meet specific enterprise requirements. In instances where modifications are made, there is no compulsion to disclose the modified source code when redistributing the software, whether it is integrated into proprietary products or offered as a standalone application. The Apache Software Foundation, the custodian of the license, is renowned for its commitment to nurturing open-source communities, contributing to a robust and supportive ecosystem for the software.

With regard to horizontal scalability, the framework is engineered to manage augmented workloads through the allocation of additional resources. The network's capacity to process an increased volume of transactions is facilitated by the distribution of workload across numerous peer nodes. The framework's architecture is inherently distributed, with nodes dispersed among various organizations and within an organization across multiple peer nodes. Scalability is further enhanced by a partitioning mechanism (implemented through Channels), which permits the integration of additional nodes into specific channels without impacting the network at large. Nodes are capable of being dynamically incorporated or excised from the network, thereby maintaining transactional continuity and enabling the network to adjust to fluctuating resource demands. Additionally, the chaincode endorsement policies within Hyperledger Fabric allow for transactions to be endorsed by a select cohort of peers, optimizing the transaction validation process [60].

The specifics of HLF are highlighted through the proposed conceptual model for realizing a network in the mining industry for sharing electric transport data on the fleet condition, capacitor charge level, traffic management, payment, and transported material quantity. The difference is that through the means of transport and their load, the efficiency of mining can be determined, the amount of material mined, the causes of damage, and others can be taken into account. Based on the reasons given, the main information flows for the mining industry would be material quantity, loading status, technical status, repairs, finance, and employee pay.

3. Results and discussion

To monitor the described information flows, management channels must be differentiated. Their

Table 2. Basic parameters of known platforms.

DLT platform	Type	Block creation time	Energy consumption	Consensus
Bitcoin	public	10 min.	high	PoW
Ethereum	public	15 s	high	PoW
EOS	public	0,5 s	no data	DPoS
Cardano	public	20 s	no data	Ouroboros
Fabric	private	0,5–2 s	very low	Modular
Sawtooth	private	no data	very low	PoET (Intel SGX)
IOTA	private	settings	very low	Tangle
Multichain	private	settings	very low	Distributed consensus
Corda	private	0,5–2 s	very low	Notary nodes
Waltonchain	public, private	30 s	low	WPoC

users will be various participants in the mining enterprise's network.

Therefore, for the transport sector of a mining enterprise, the information data is examined in five channels – production, electricity, battery charging, technical condition, and finance. The parameters included are based on the regulatory requirements of procedure 2017/2772 (RSP), such as vehicle registration and administration, mileage verification, smart insurance, and electric vehicle charging [30]. The specified channels and participants are not final and may change as necessary, which is consistent with the functionality of the selected HLF [29].

3.1. Amount of transported material

Track the routes of the cars in order to monitor the amount of transported cargo. Through this channel, the route of the electric trucks is managed by the dispatcher so that loading, transportation of goods, and unloading are safe, without detection of electric vehicles (EVs) and with minimal consumption of electricity, which is a step towards achieving a circular economy as a means of sustainable development. For this purpose, it is necessary to observe the following parameters:

- route;
- the change of the map when moving the stake (working face), road, reporting, and regulating devices;
- place and time of loading the electric trucks;
- electric truck number;
- place and time for unloading the electric trucks.

These functions are reported and, if necessary, adjusted by a dispatcher. By the number of electric trucks that have passed with the corresponding load, the quantities of ore and preparation carried by the driver (observed by the dispatcher) can be calculated, and his efficiency or even payment can be determined. In [57], a communication scheme is proposed for the reports of the mining company to the regulatory bodies "Zemni Nedra" agency, concession, etc (Fig. 2.).

Figure 2 shows that the dispatcher receives data on the status of the extracted quantities of material and the cars. The material flows defined in this case are loaded material quantity, unloaded material quantity, condition of a deposit, car location, road map, and battery status. The dispatcher approves the data, and it is fed to the DLT system. Depending on the defined organizations and channels for the distribution of transactions, the prepared blocks are submitted to the corresponding anchor nodes. After approval, anchor nodes replicate the data to the rest of the nodes in the organization via the Gossip protocol. The importance of the Gossip protocol to improve throughput among 100 peers is illustrated in Table 3 according to [60].

Three nodes are proposed on the diagram, one of which is the mining company. It decides which data it will share with the government and concessions

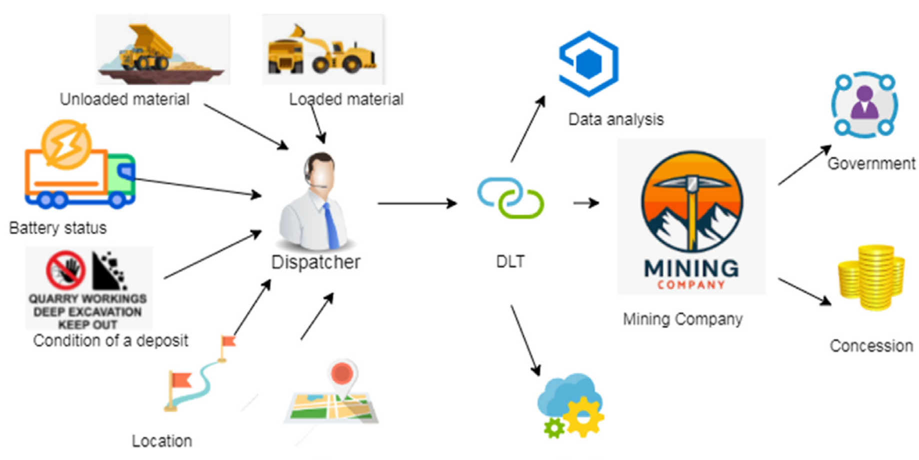

Fig. 2. Communication for excavating data.

Table 3. Throughput among 100 peers with or without Gossip protocol.

Performance (Mbps)	240	98	108	54
Throughput (tps) without Gossip	1914/2048	1914/2048	1914/2048	1389/1838
Throughput (tps) with Gossip	2553/2762	2558/2763	2271/2409	1494/2013

office. Through another channel, it sends data for analysis and, if necessary, for additional quality control or regulatory requirements to another organization.

Because the size of the blocks formed is important for latency and throughput in Hyperledger Fabric there are published results on changing the block size experiment from 0.5 MB to 4 MB have been published. The parameters are examined in output (spending) and input (mint) states. In spending additionally checked whether, for all entered states, a readset entry was created, it was added to the record set and marked as deleted. According to the results of Table 4, the peak throughput at average end-to-end latency (e2e) is noted. Throughput increases for block sizes above 2 MB, but latency degrades. These experimental data should be taken into account when configuring a new system [60].

In the indicated scheme, two streams for communication with participating actors stand out: the electric truck transmits data on the distance traveled in one channel, and the second transmits data about the presence of an accident. In the first channel, it communicates with the dispatcher the electronic signs that indicate the route, the time to pass, stop and change the working face, and the amount of material. After the electric truck is loaded with enough material, it reaches the unloading point, and there, the unloaded quantity is measured. The data is confirmed by a dispatcher. In a second channel, the truck communicates with the dispatcher and the accident repair company. The need for two channels arises because there may be a change in channel settings or subscribers.

For example, when a working scope is changed, the corresponding vehicle must communicate with new participants. This is precisely an example to prove that Hyperledger Fabric, which enables multi-channel communication, is suitable. The participating organizations (nodes of the network) are the transport vehicle, the loading vehicle, the sign (probably assumed to be one, but the nodes are many more), finally, the unloading scale, and the mining company, as shown in Figure 3. These five nodes are called peers – P1, P2, P3, P4, and P5, respectively. In the ore delivery channel, they are recognized by Member Service Organization (MSP) C1, C2, C3, C4, and C5 certificates, respectively. This is an organization that issues validation certificates that certify that the relevant devices can transmit data on that channel.

The listed participants have the same states of the distributed ledger (L1) and have previously accepted the same rules of communication, i.e., own the same smart contracts (SC1). They contact through applications App1 and App2. Noticed in the diagram is node O. This is an orderer that forms the transactions, packages them, and verifies that all voting nodes have confirmed the transaction when it changes. It has no chain code installed.

If the route changes or an obstacle appears, it is necessary to include a new participant. This is a new electronic road sign. This changes the smart contract by defining the sign's rights in the network. It is assumed that he will be without authority to approve transactions. The chain code is then updated and the new sign communicates with the electronic vehicle. The new state is recorded in the L1 ledger.

When the state of a character changes, P5 sends a proposal for it. This may be a temporary status "Attention: Repair!". The ordering node sends a transaction proposal. After approval by P5, the transaction list is returned to P3 (marker, signs). The orderer checks the signature and packages the made

Table 4. Impact of block size on throughput and latency.

Kind peer	Block size (Mb)	Throughput (Tps)	Latency (ms)
Mint-throughput peer	0,5	2200	600
Mint-throughput peer	1	2450	660
Mint-throughput peer	2	3000	810
Mint-throughput peer	4	3010	800
Spend-throughput peer	0,5	2600	760
Spend-throughput peer	1	3000	800
Spend-throughput peer	2	3200	850
Spend-throughput peer	4	3100	840
Mint-e2e-latency peer	0,5	500	150
Mint-e2e-latency peer	1	700	200
Mint-e2e-latency peer	2	1900	500
Mint-e2e-latency peer	4	2500	700
Spend-e2e-latency peer	0,5	800	200
Spend-e2e-latency peer	1	1400	400
Spend-e2e-latency peer	2	2000	600
Spend-e2e-latency peer	4	3500	1000

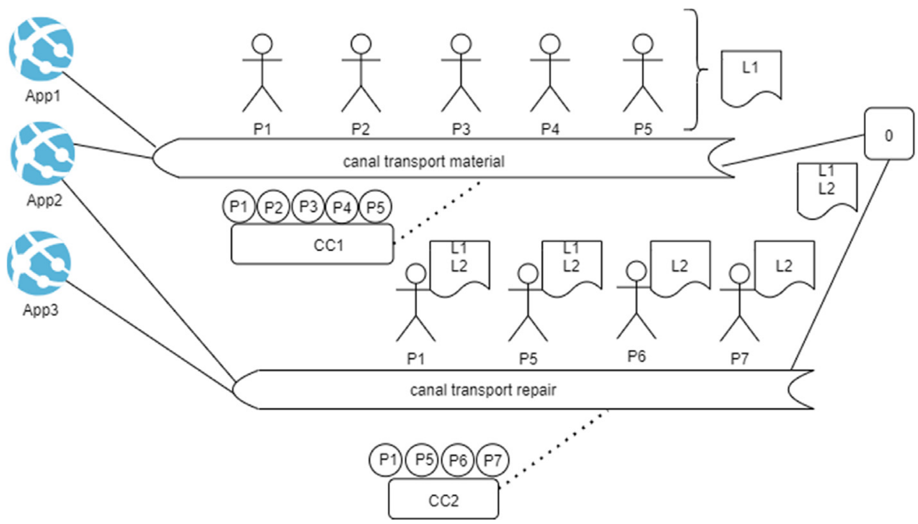

Fig. 3. Communication scheme material transfer.

offer into an envelope with other transactions. Upon receipt of the envelope, the electric truck verifies this signature together with the unloading node (in this case, it is engaged as an approver because the approver nodes are pre-defined in HLF), validates it, and sends a status change message. Approval of the transaction follows, with the ordering node checking that all voting nodes have been approved. In the case of approval, the peers check that there is no other state recorded, and if not, approve the existence of a new sign as the new shared state of the ledger. Another example is changing the characteristics of a road, which becomes more difficult. As a result of the change, measures are taken to correct the speed of the electric truck. Then, according to the described procedure, the new speed value is added to the storage nodes. A correction of the daily transfer rates follows.

The stream splits when the vehicle breaks down. It then communicates with the repair company, the mining company, and the dispatcher. Traffic signs, as well as loading and unloading equipment, are not involved in this communication. Then the truck is P1, the repair company (P6), the performance inspection authority of the delivery company (P7), and (P5) the mining company. They share data about the type of damage, the time to repair, and the type of repair. This data can be used for subsequent analysis of the types of damage in certain activities. Thus, electric truck 1 and the mining company now have two books, the second of which records the types of repairs, as shown in Figure 4. The repair period is counted, and material is not carried over. In this communication, nodes P1 and P5 own two ledger states (L2) and communicate according to two smart contracts.

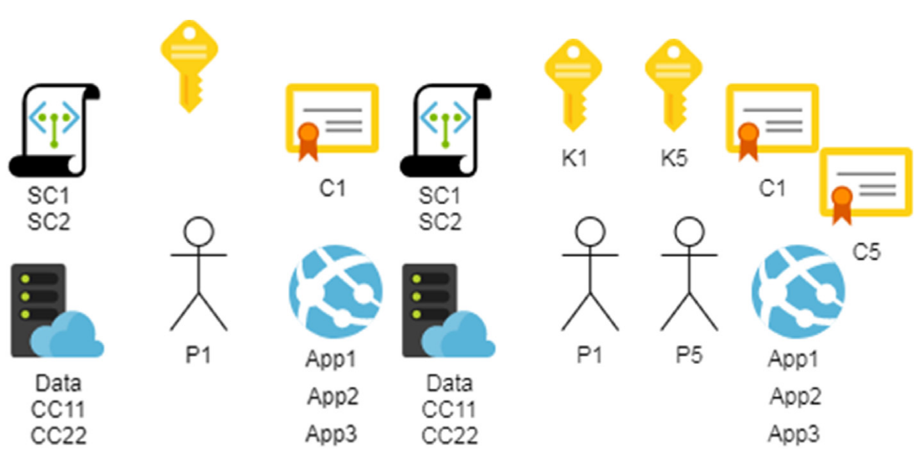

Fig. 4. Certificates, smart contract and ledgers of electric truck, and mining company.

The procedure thus described shows how participants P1, P2, P3, P4, P5, P6 and P7 can share heterogeneous data in several channels, which in this case are two. Each state change is added to the ledgers they are subscribed to (L1 and L2). The presence of several streams of communication implies the installation of a multi-channel platform. Since data is exchanged that is confidential and sensitive to the mining company and the power company, the participants must be known ie. previously accepted on the network. A platform that meets these requirements is Hyperledger Fabric (HLF).

3.2. Monitoring of consumed electricity

Another channel shares power quality data, which is not shown in the diagram. It also includes the consumption of other equipment, such as rubber conveyor belts, electric hoists, and others. In it, the energy users, the mining company, and the power supply company communicate. The channel is necessary because the mining company is a large consumer, and when starting or stopping work, the electricity supplier must be notified. Parameters that are exchanged between the two are current I, [A], U [V], P [W], cosφ, time, and others. Through these values, the quality of supplied and consumed electricity is monitored, which is an indicator of a change in the way the fleet is managed during its reduction. These data are not included in the scheme because they were not analyzed in the study.

The proposed data in the information flow is not final and it can be changed according to the specifics of the production or the regulatory basis. For example, according to the EN 50160 and IEEE Standard 519-1992 standards in force in Bulgaria, the level of harmonics for lighting objects is measured but not for industrial. Harmonics are known to reduce the service life of electric motors due to losses in the rotor and stator; losses in the material – iron and copper; heat and energy losses; skin effect; engine shaft twists, fluctuations, and vibrations. If necessary, this parameter can also be included in the communication channel.

3.3. Status of charging stations and battery charging

The topic of blockchain environment, consensus techniques, saboteur resistance, tolerance, transaction finality, demonstration, leader election, performance scalability, energy efficiency, and application areas is discussed in science [29]. Various parameters are available for investigation. In the case of forming an information flow for each electric vehicle, the charging level of the capacitor batteries is monitored by measuring the energy capacity Wh, delivered power, charging time, time to use up to a certain percentage of the battery. Monitoring these parameters is important because they calculate the energy efficiency, monitor the technical health of the battery according to the number of cycles, and prevent the car from stopping due to lack of energy.

In another channel, the status of the charging stations is monitored. Figure 5 shows the parameters involved – time, energy indicators, station number, and battery status. The data is verified and submitted to the mining company.

In the figure, it is visualized that the dispatcher receives data about the status of the electric cars.

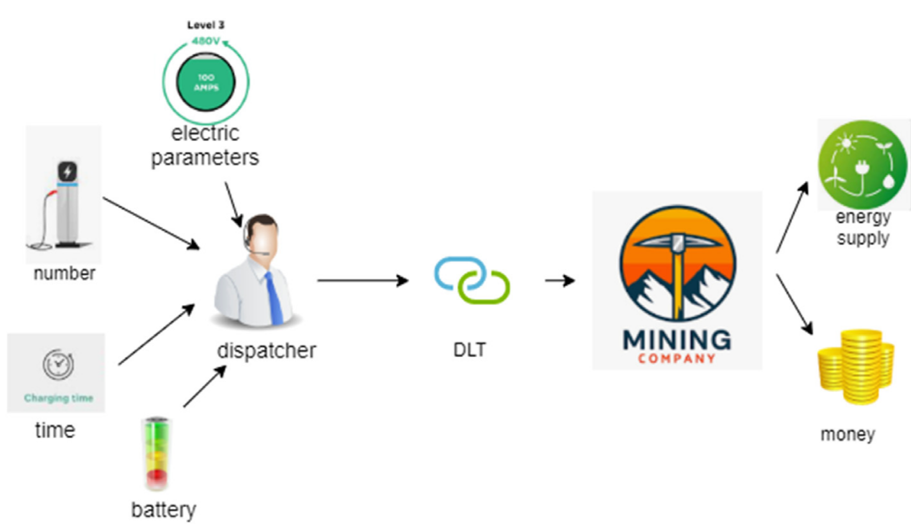

Fig. 5. Parameters of charging stations.

The material flows defined in this case are electrical parameters for the consumed energy, number of charging stations, charging time, and the condition of car batteries. According to the procedure described above, the dispatcher approves the data, the blocks are prepared, and they are submitted to the corresponding reference nodes. In this case, there is one node that decides what data to submit to the electricity company for payment.

The main sample application creates a set of 5 unique assets for each charging station, with tier 3 high power and fast charging ones chosen for the mining sector conditions. These charging stations differ in model, power, and current. In this case, we are not interested in the brand, and it is not included among the unique assets. Also, the power quality parameters of the AC to DC conversion are not investigated. This can be done additionally. Some charging stations have different statuses, such as Green/yellow/red/blue, and this data is not included in this case for sharing. The main parameters are current I, [A], U [V]; charging power: [kW], time [min]; charging station and free station [37]. When they are created, the ledger looks as shown in Table 5.

It can be seen that the ledger has four states with keys ASSET1, ASSET2, ASSET3, and ASSET4. There are two blocks, with number #0 being the genesis block and the second one with #1 having four transactions: T1, T2, T3, and T4. The world state contains the states of the charging stations with the parameters of the delivered energy. This means that station #1 is free and has been charging for a certain time with a current of 200 A, while station #2 is more powerful and currently continues to work. By these parameters, the energy they gave off can be determined. Currently, block 1, which is linked to block 0, contains transactions T1, T2, T3, and T4. These transactions are version 0, meaning they have not been updated since they were created, as shown in Figure 6. When station #2 is released, there will be a new updated status and the new status for T2 will be

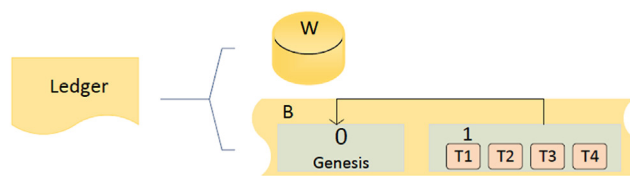

Fig. 6. Two blocks of the global state of the distributed ledger.

recorded in the blockchain — free and change of working time — 120 min. The state of the ledger will take the form from Table 6.

3.4. Technical condition

The technical condition of the vehicles depends on the hours of operation, number of courses with ore, number of courses empty, and distance traveled. In this case, it is necessary to separate the components of the electric car into different channels — batteries, electric motor, LPG, tires, electronics, and charging stations. For each component, the necessary sensors are placed, which send information to the "Repairs" sector. All sensors send a signal to the system, and when a critical point is reached, the vehicle is taken out of service and brought in for repairs. For example, the state of the battery is monitored through the values of Energy density (Wh/kg and Wh/L); Power density (W/kg and W/L), and Cycle life: The number of complete charges/discharges cycles until the end of life. Sensors for temperature, condition of bearings are placed for the electric motor, insulation resistance, and others are periodically tracked.

When repairing the work done, the materials used, such as changing the battery or tires, replacing parts, making new ones, filing or welding, etc., are recorded. Information about required parts and materials is sent to the suppliers, who, after delivery of the relevant ones, record the new status. All records are submitted to the mining company in the direction "Repairs" and according to them, the

Table 5. Shared charging station status ledger.

Key = asset4, value = {current:200 A, voltage: 220 V, charging power: 120 kW, time: 60 min, station: 6, state: free}	Version 0
Key = asset3, value = {current: 400 A, voltage: to 920 V, charging power: 300 kW, time: 60 min, station: 4, state: free}	Version 0
Key = asset2, value = {current: 320 A, voltage: to 920 V, charging power: 320 kW, time: 90 min, station: 2, state: work}	Version 0
Key = asset1, value = {current: 200 A, voltage: to 920 V, charging power: 120 kW, time: 30 min, station: 1, state: free}	Version 0

Table 6. Shared charging station status ledger in version 1.

Key = asset4, value = {current: 200 A, voltage: 220 V, charging power: 120 kW, time: 60 min, station: 6, state: free}	Version 1
Key = asset3, value = {current: 400 A, voltage: to 920 V, charging power: 300 kW, time: 60 min, station: 4, state: free}	Version 1
Key = asset2, value = {current: 320 A, voltage: to 920 V, charging power: 320 kW, time: 120 min, station: 2, state: free}	Version 1
Key = asset1, value = {current: 200 A, voltage: to 920 V, charging power: 120 kW, time: 30 min, station: 1, state: free}	Version 1

payment is made. After repairs are done, workers share data about the work done and the time it took them in another channel.

3.5. Funds

The financial flow of the mining company is on the one hand to the banks, the companies to which they sell production; the regulatory and financial authorities such as the National Insurance Institute and the National Revenue Agency, the suppliers of parts and raw materials – fuel, electricity; vehicle insurances, wireless communication subscriptions. On the other hand, it is for the management of the car fleet, where the values are included – funds for repairs and spare parts, consumed electricity and fuel, consumables, tires, salaries and training of personnel, and others. The scheme is not visualized because it is described in [57].

In this communication, the payment of the workers is also included as an option [12]. Data on completed work or hours are entered by workers (mining slope, accounting, repairs) into the system through an application. They have an open account and new entries are added. Through the mining company program system, their rewards are determined by the accepted exchange unit – tokens, bitcoins, etc. The data is verified by a dispatcher. The verified data in the form of remuneration through the application is visualized on the worker's device. Earnings are shared unilaterally with the National Insurance Institute, the National Rvenue Agency. The mining company can make entries in the system.

The data measured by the sensors must be stored in a database, from which the necessary for each communication channel can be extracted and sent to the relevant actor.

4. Conclusions

In the near future, the deployment of electric vehicles and their management through a SMART network is inevitable. For every city, country, and enterprise, the inclusion of electric vehicles in an urban or industrial environment will be a challenge. In contrast to the geographical remoteness of countries when the first electric car was invented, the world now has globally connected communication networks. In the era of the fourth industrial revolution on the way to realizing Industry 5.0, everyone using the latest technologies has an advantage. This not only means fast data transfer but also the implementation of clean and waste-free technologies. Therefore, the article briefly proves the advantage of introducing 4.0 technologies with a perspective to 5.0 not only for management and increasing efficiency but for realizing sustainable development through a step towards really working a circular economy.

For this purpose, modern information technologies for the implementation of intelligent management and a smart mine are specified. It has been found that the conditions of the mining industry require the use of electric vehicles with a high level of automation. Suitable electric vehicle power systems such as BEVs or P.H.E.V.s with series architecture are recommended. The main technologies for implementing such innovative projects are indicated, highlighting the distributed ledger technology for data sharing. The advantages and challenges of blockchain implementation are classified.

Based on the experience of the major transport companies, a DLT network was chosen for the management of electric vehicles. To provide the multi-channel communication required in this case, the Hyperledger Fabric platform is recommended. Conceptual models were made of the defined communication channels suitable for the mining company – the amount of material, consumed electricity, battery charging, financial flows, and equipment serviceability. Realizing multi-channel communication in ore mining and electric vehicle health tracking is demonstrated via Hyperledger Fabric. A conceptual model for monitoring the amount of mined ore, the repair status, and the status of charging stations is proposed.

Naturally, the proposed information flows and use cases are not final and can be changed according to the organizational structure, activity, production parameters, and the wishes of the individual customer. The developed algorithm for the use case helps to clarify the stages of renovation of the vehicle fleet of any enterprise, and the conceptual models visualize the information flows. The document proposes basic steps up to the smart contract preparation stage when implementing a real prototype. For a working solution, a network with certain relations and roles of the members, a smart contract, and a consensus mechanism must be implemented. With the suggestions thus made, I believe I am helping to prepare the concept for the implementation of DLT and specifically Hyperledger Fabric in mining.

Directions for future research are optimization of information flows, advanced consensus mechanisms providing greater fault tolerance, faster distribution of blocks, and improved energy efficiency. It is necessary to pay special attention to the components of the system responsible for registering events and reflecting complications and accidents.

This study is the result of the ongoing work of the team from the 2020 report Exploring the possibilities for the application of DLT using blockchain in data sharing in mining and electricity generation from biogas MEMF-164.

Ethical statement

The authors state that the research was conducted according to ethical standards.

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Conflict of interest

The authors declare no conflict of interest.

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