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Implementing Lean Manufacturing Method to Achieve an Effective Maintenance System in the Mining Company

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Abstract
This article deals with the maintenance process in the selected mining company. It investigates the maintenance process over digitalization and optimization as a pillar of Industry 4.0. The main goal of the research in this article was to design an effective maintenance system for the material and spare parts. The object of the research was the mining company in Slovakia that focuses on the maintenance process of mining machines in the frame of a wide spectrum of mining activities. Economic quantitative methods were used in solving the research, observation for spare parts, a graphical method for spare parts layout, and software application. The relevance of this scientific research was related to the innovation of the maintenance process with large barriers. We suggested a document, a record of spare parts, a flow chart for supply, a model of a maintenance system, and a model of controlling. The conclusions of this mining company can be recommendations for other mining companies around the world.

Keywords
maintenance, efficiency, spare parts, lean manufacturing, costs

Introduction

In the context of the mining industry, where the maintenance process plays a pivotal role, integrating the Lean manufacturing method and Industry 4.0 principles emerges as a strategic approach. Balog et al. (2021) commented that lean manufacturing emphasizes the elimination of waste and continuously improving processes, aligning seamlessly with the goals of Industry 4.0, which strives for intelligent, interconnected, and data-driven manufacturing systems. By amalgamating these methodologies, the aim is not only to enhance the efficiency of maintenance processes but also to foster a culture of adaptability and resilience within the mining company. Abidi et al. (2022) present the maintenance process as a supporting process within the IPO chain of every business entity. It is essential for eliminating workplace hazards and creating a safe working environment, as well as the functionality of machines and equipment, means of transport, and arrangement of the workspace.

Lastra et al. (2022) said that the overall maintenance activity consists mainly of the supply of spare parts and consumables, technology, and overhead material to perform all maintenance activities. Rajput et al. (2020) comment that maintenance as a process within the Industrial Revolution Industry 4.0 is focused on digitalization in the supply process of spare parts and materials. Kecskemet et al. (2009) supply information about optimizing the maintenance system connected by minimizing the costs associated with maintenance performance and introducing an efficient method of storing spare parts and materials. Tsou et al. (2021) commented that embracing digitalization becomes imperative for staying competitive and ensuring sustainability as the mining sector evolves.

Kovalčík & Balog (2021) said the utilization of advanced technologies such as the Internet of Things (IoT) and data analytics can revolutionize how maintenance tasks are planned, executed, and monitored. Real-time monitoring of equipment health, predictive maintenance algorithms, and intelligent inventory management are pivotal components of this digital transformation. Richards et al. (2019) commented that integrating Industry 4.0 principles into the maintenance system not only streamlines operations but also contributes to the overall competitiveness based on top KPI indicators of performance and longevity of the mining company in a rapidly changing global environment. Suchánek et al. (2015) commented that the relationship between digitalization and optimization in the maintenance process cannot be overstated. Industry 4.0 offers the opportunity to move beyond reactive and scheduled maintenance approaches to predictive and condition-based maintenance, which is an advantage for customer satisfaction and product quality. Markulík et al. (2022) presented that by harnessing the power of data analytics and machine learning, mining companies can anticipate equipment failures, schedule maintenance activities more efficiently, and reduce downtime. Lachvajderová & Kádárová (2022) comment that this paradigm shift from traditional maintenance practices to a proactive, data-driven model is a cornerstone in achieving cost savings and maximizing the lifespan and performance of critical mining assets.

The paper's primary goal is to design an effective maintenance system for spare parts for mining companies with an orientation to the pillars of Industry 4.0. Selvik et al. (2021) presented that Industry 4.0 represents an innovative economy based on digital connectivity that will improve businesses' efficiency, productivity, and performance. Economic crises do not influence digitalization in the maintenance area, commented Lachvajderová & Kádárová (2022).

Femandes et al. (2021) commented that generating profit and cost-minimizing is part of implementing business development oriented to solving limitations in energy, natural resources, and the environment regarding sustainable development. Teplická & Straka (2020) presented that the pillars of Industry 4.0 in an effective maintenance system are optimization, innovation, and digitalization.

Effectively managing spare parts, optimizing logistics processes, and ensuring streamlined storage are critical aspects of achieving comprehensive maintenance efficiency within the framework of Industry 4.0.

In the era of Industry 4.0, maintenance processes undergo a profound transformation, necessitating a shift in traditional paradigms to meet the evolving requirements of this digital age. The integration of Industry 4.0 principles imposes a set of distinct demands on maintenance practices within various industries, including mining. Industry 4.0 places a premium on intelligent and automated inventory management systems.

Kebo et al. (2015) presented the utilization of technologies such as RFID (Radio-Frequency Identification)or barcoding. The mining companies can track the real-time status and location of spare parts within the warehouses, which is beneficial. Automated inventory systems, integrated with data analytics, enable predictive stock replenishment, reducing the risk of stockouts and minimizing excess inventory. It ensures that necessary spare parts are always available and saves costs by avoiding overstocking. Malega et al. (2017) presented that in the Industry 4.0 landscape, the supply chain becomes a digitally interconnected ecosystem. Mining companies should invest in digital tools that facilitate seamless communication between suppliers, manufacturers, and maintenance teams. It includes the integration of digital platforms for procurement, order processing, and communication with suppliers. A digitized supply chain not only enhances transparency but also enables quick response to changing maintenance requirements, contributing to the overall effectiveness of the maintenance system.

Husár et al. (2023) said that maintenance is a process that means maintaining the workplace, equipment, and machinery in such a condition that they perform their function safely and that their overall condition does not deteriorate. This approach is part of lean management in mining and industrial companies. Maintenance as a process within the Industrial Revolution Industry 4.0 focuses on digitalization. A computerized maintenance management system or CMMS (Figure 1) is software that centralizes maintenance information and facilitates maintenance processes.

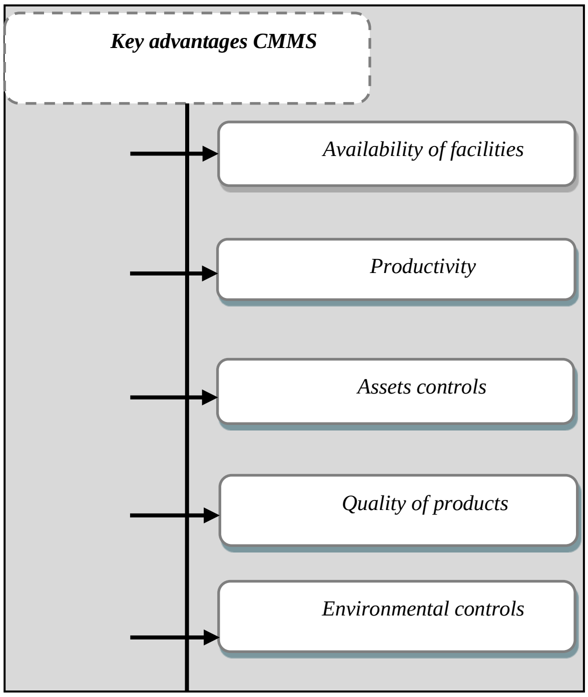

Fig. 1. Key advantages of CMMS system. Source: own source

Bashar et al. (2020) presented the base instrument of effective maintenance as regular maintenance, which prevents sudden, unexpected breakdowns. Gonzalo et al. (2022) presented that the effective maintenance system includes all technical, administrative, and managerial activities during the object's lifetime, which is intended to maintain it in a state where it can perform the required function to protect it from failure or limitation of its functionality. Markulík, Petrík, Blaško, Palfy & Girmanová (2022) presented that there are eight basic maintenance indicators: planning effectiveness, inventory of maintenance work, overtime clock, downtime, budget deviations, work performance, maintenance costs, and correct maintenance costs. Supplying spare parts to mining companies is part of the maintenance process. A machine's spare part can be used as a separate replacement for the same worn or damaged part during repair; it wears out faster than the entire machine and its service life is shorter than the machine's service life. Industrial Revolution 4.0 brings the application of artificial intelligence in manufacturing, which is becoming common. Maintenance is one of the essential activities in the manufacturing process, and the requirements of Industry 4.0 as a digitalization are substantial.

Abidi et al. (2020) said that predictive Maintenance (PdM) has become necessary in industries and mining companies to decrease maintenance costs and attain sustainable operational management. The applicability of additive manufacturing to spare parts, specifically in preventive maintenance, is a new technic for improving preventive maintenance. This technique is always used in the automotive industry. Maintenance is essential because it enhances the lifetime of machines. By introducing maintenance, the lifetime of machines can be extended. Maintenance should be planned to accurately estimate the machine failure period to reduce the risk of accidents, financial losses, and human casualties. A computerized maintenance management system or CMMS is software that centralizes maintenance information and facilitates the processes of maintenance operations. Richards et al. (2019) said that the CMMIS, or computerized maintenance management information system, is found in manufacturing, oil and gas production, power generation, construction, transportation, and other industries where physical infrastructure is critical. CMMS helps optimize the utilization and availability of physical equipment like vehicles, machinery, communications, infrastructures, and other assets. Typical features of computerized maintenance management systems include scheduling of workers, preparatory works, maintenance work scheduling and management, preventive maintenance management, calculation of maintenance costs, technical documentation management, historical tracking of all created work orders, which can also be sorted by date, person, response; management of spare parts.

Quality is a critical criterion for evaluation in manufacturing firms. Markulík et al. (2022) presented that producing a final product that can meet customer requirements is essential in a sustainable supply chain system to reduce costs, increase productivity, and provide high-quality products.

Material and Methods

To optimize the maintenance process within the mining industry, we employed a systematic and comprehensive approach, integrating Lean Manufacturing principles and using digitalization as a pillar of Industry 4.0. Figure 2 presents the algorithm of steps of our scientific research in a selected mining company.

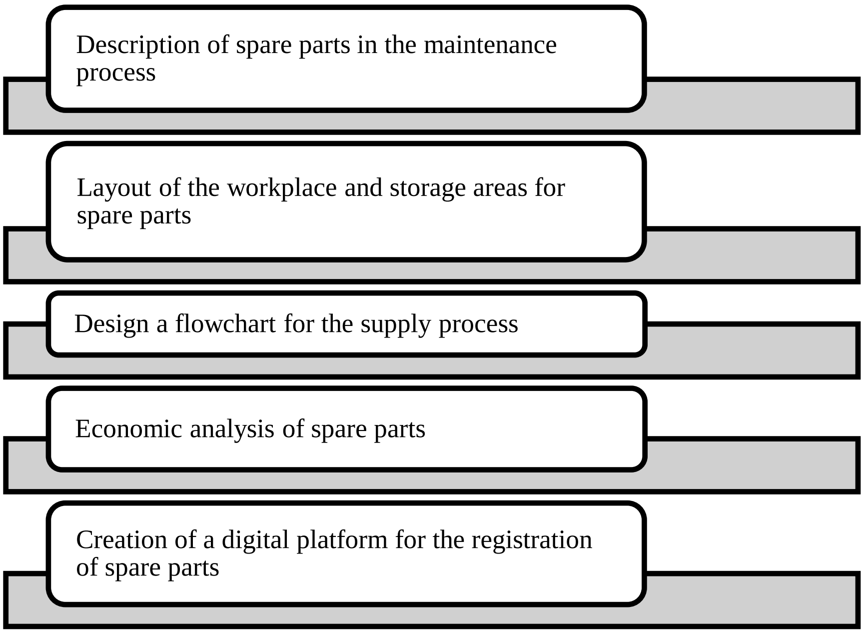

Fig. 2. Algorithm of the research in the maintenance process in the mining company. Source: own source

The main purpose of the research was to increase the efficiency of materials and spare parts for maintenance activities in mining companies. The primary goal of our research was to design an effective maintenance system based on the principles of Industry 4.0. with a particular emphasis on digitalization and optimization. The mining company in Slovakia served as our research point, precisely honing in on the maintenance processes associated with mining processes such as mining, crushing, sorting, milling, and packing. The maintenance process plays an important role in the frame of those processes.The actual situation of the maintenance process in a mining company has significant shortcomings. The maintenance system is not effective, and the priority of the maintenance is corrective maintenance, not preventive maintenance.

The main barriers are:

1. The large quantity of spare parts and materials is not specified in the financial accounting through analytical evidence.
2. The storage of spare parts is not systematic. It has missing labels for spare parts and a logical layout.
3. The material supply process has no punctual algorithms.
4. Maintenance documentation of spare parts is not clear. This documentation does not show the material deficit in the warehouse.
5. Maintenance costs have progressive trends that depend on many spare parts, suppliers, price of spare parts, and arrival time of material from suppliers.
6. The total maintenance system has no control and performance indicators that are monitored.

Analytical Method for Spare Parts:

We research the maintenance process using an analytical method to check spare parts. This part involved creating a complex list, assigning unique identifiers, and successfully processing this information within the SAP management system. Through this step, we sought to establish a foundational understanding of the spare parts landscape, a crucial element in the subsequent design of an efficient maintenance system.

5S Method for Workplace Organization:

The key role of the mining company in enhancing productivity and safety was the implementation of the 5S method to standardize and visualize the layout of workplaces and storage areas for spare parts. This method, encompassing Sort, Set in order, Shine, Standardize, and Sustain, served as a model for workplace organization. The careful application of this method not only contributed to a well-ordered work environment but also encouraged efficiency and safety, aligning with the main goals of our research.

Flowchart Design for Supply Process:

A crucial step in our methodology involved designing a flowchart for the material supply process within the maintenance framework. This visual representation aimed to streamline and enhance the transparency of material procurement processes, contributing to a more seamless and efficient supply chain.

Economic Analysis and Formulas for Structure Determination:

In tandem with the steps mentioned above, we conducted an economic analysis to decipher the development trend of the value expression of materials and spare parts. Formulas 1 and 2 were employed to determine the structure of materials and spare parts within the maintenance process. This quantitative analysis provided valuable insights into cost dynamics and material composition, laying the groundwork for strategic decision-making.

Formula 1 (Index):

$$I = \frac{C1}{C0} \tag{1}$$

Formula 2 (Structure):

$$S = \frac{Cj}{Cc} * 100 \tag{2}$$

where: C – costs, (0,1) – time period, Cj – unit cost, Cc – total cost.

Creation of a Digital Platform:

A significant aspect of the methodology of this article was creating a digital platform for registering spare parts. This step involved generating detailed documents for material management within the maintenance process. This digital infrastructure facilitated efficient documentation and served as a base element for the following controlling model.

Results

Through a comprehensive investigation of the maintenance process within the mining sector, we have uncovered valuable insights and strategic innovations that align with our main goal. The main goal is to base the filling on implementing Lean Manufacturing and Digitalization as integral components of Industry 4.0. The multidimensional results are orientated in three key domains: the description of spare parts, the layout optimization of workplace and storage areas, and the economic analysis of spare parts.

Description of Spare Parts:

Our initial step involved a meticulous description of spare parts within the maintenance process in the financial accounting through analytical evidence (401-421). A detailed list was curated, with each spare part assigned a code according to financial accounting protocols (the code of account 501). The analytical accounts (401-421) introduce the type of material and spare parts and their name. This information was systematically processed in the SAP management information system of the selected mining company. This process laid the basis for a comprehensive understanding of the spare parts area, facilitating subsequent analyses and optimization strategies and the cost-controlling model for the maintenance process. This approach improved the evidence of the spare parts and material as a support instrument for supply.

Table 1 Record of spare parts in the maintenance process. Source: internal sources of SAP system

501 401 repair spare parts	501 402 electrical installation material 501 403 bearings and housings 501 404 plumbing material 501 405 building material 501 406 plastic material 501 407 profil material 501 408 pipes 501 409 connecting material 501 410 oxygen in bottles, gas 501 411 refractory material 501 412 spare parts assembled 501 413 tires 501 414 flanges 501 415 knee bends 501 416 other water supply material 501 417 techno grates 501 418 reprographic material 501 419 fittings, pipes 501 420 light bulbs501 421 tubes

The layout of the workplace and storage areas for spare parts

In this part, we applied the 5S method standardization and visualization, as well as eliminating waste in the workplace. The picture below illustrates an implemented model of 5S for spare parts and material in the storage. Unnecessary spare parts and material in the warehouse were disposed of, marking labels were made for an accurate overview of spare parts, and a standardized procedure for receiving and issuing material was introduced. Implementing the 5S method was pivotal in enhancing the organization of workplaces and storage areas for spare parts. This methodology went beyond mere standardization and visualization; it became a catalyst for waste elimination, marked by the disposal of unnecessary spare parts and materials in the warehouse. The introduction of marking labels ensured an accurate overview of spare parts, while a standardized procedure for material receipt and issuance was instituted, contributing to operational efficiency.

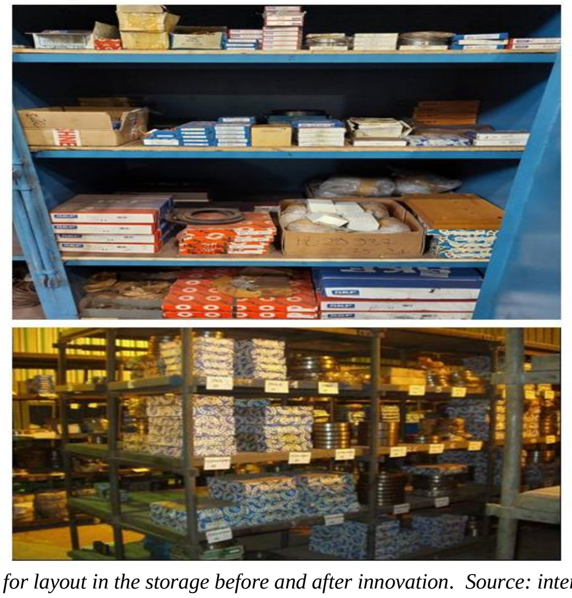

Fig. 3. 5S method for layout in the storage before and after innovation. Source: internal sources

Material Supply Process Flowchart:

The research resulted in the development of a comprehensive flowchart that delineates the material supply process within the maintenance framework. This model, illustrated in Figure 4, serves as a standard for implementing spare components and operating materials supply. Processes within the flowchart, from material request to purchase, receipt, and quality control, offer a systematic and streamlined approach to material management, contributing to operational effectiveness.

The flow chart for the material supply process is as follows:

Z - the beginning of the process, 1. Submitting a request for material, 2. Decision on securing the material, N - if the material cannot be secured K - process closes, 3. Specification of the material, 4. Is the material standardized? A – YES following 9, 5. Selection of material according to the catalog and supplier, N – NO following - 6. Request for drawing documentation, 7. Completion drawing documentation., 8. Inspection of material in warehouses, 9. Issue of the document, 10. Decision on approval of the document, N- NO - to back 9, A – YES - 11. Approval of document, 12. Submission of the document to the purchasing department, 13. Purchase of material, 14. Receipt of material into the warehouse, 15. Incoming quality control of material, N – NO – back to 13, A – YES - 16. Collection of material from the warehouse, 16. K- end of process.

This flow chart allows you to implement the material ordering process according to certain steps, while the importance lies mainly in decision-making situations that represent downtime for this process. With this diagram, the process is accelerated, and there is no downtime.

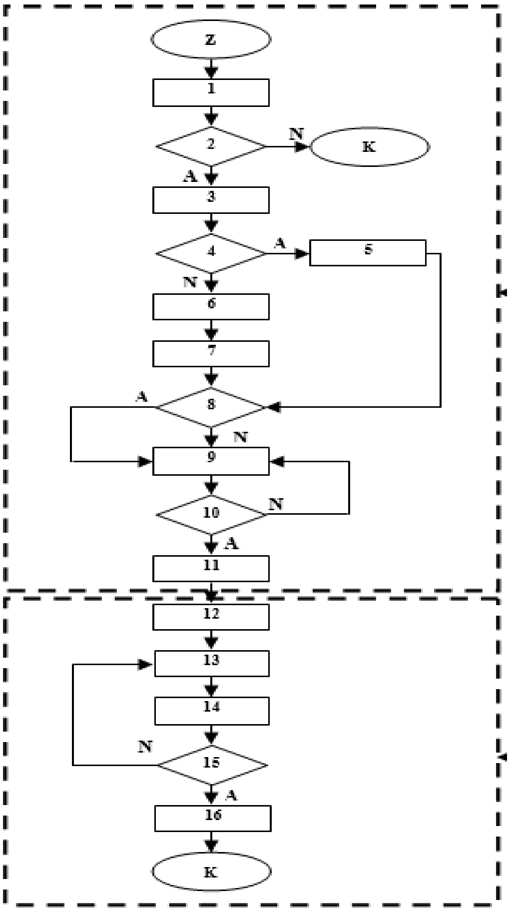

Fig. 4. Flow chart model for supply process. Source: own source

Economic analysis (Table 2) of spare parts - in this part, we will analyze the development trend of the value expression of material and spare parts; we will determine the structure of materials and spare parts in the maintenance process by formulas 1,2. Monitoring the costs of material and spare parts is important from the point of view of purchasing material and spare parts so that there is no deficit in the stock, which represents downtime of machines and mining processes, which affects the financial side of the mining company, processes, and profit level.

Table 2 Economic analysis. Source: internal sources of mining company

Costs(€)	2018	2019	2020	2021	2022
Spare parts	3 742 767	14 019 467	5 369 667	5 138 437	7 024 800
Maintenance material	1 201 640	1 383 334	1 837 634	1 561 134	2 729 800
Index spare parts	-	3,74	0,38	0,95	1,36
Index maintenance material	-	1,15	1,32	0,84	1,74
Structure spare parts	10,6%	39,7%	15,2%	14,5%	20%
Structure maintenance material	13,5%	15,8%	21,5%	18%	31,2%

The result of the economic analysis points to a significant increase in the cost of spare parts in 2020, a significant decrease in costs, and a gradual increase in costs until 2022, which may also be related to inflation and the market situation. We noticed a slight fluctuation for the rest of the material, with an apparent decrease in 2021 and an increase in 2019, 2020, and 2022. The structure of spare parts varies in the range of 10.6%-39.7%. The increase in the share of spare parts in 2019 also meant high costs. The structure for the other material was in the range of 13.5%-31.2%. The increase in material also meant an increase in material costs in 2022. The increase in costs for spare parts and other maintenance materials causes an increase in the prices of maintenance work, negatively impacting the company's operating costs. For this reason, it is necessary to look for innovative ways to optimize costs in the maintenance process.

We created a new document (Figure 5) of materials in the digital SAP platform to register spare parts. The document contains all the essential information for the order (numeric character – 3312, name: spare part, description – ball bearing, type – double row, specific code – with title, contact). The document contains the basic information such as the name of the material, the description of the material, the type of material, the specific code that we set in the first step of the spare parts description, the supplier, the plan number, the material number, the date, the price, the quantity, the number, the date of receipt, the date of release from the warehouse. The quantity of spare parts and materials is important for the level in the warehouse and the purchase of materials and spare parts. This form of documentation allows a review of the spare parts and can buy the missing quantity of spare parts just in time.

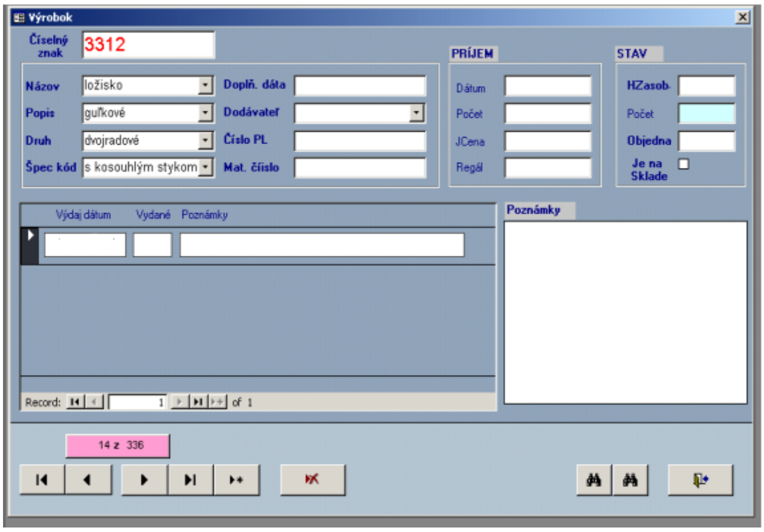

Fig. 5. Proposed new document for material in the maintenance process. Source: internal software of SAP for maintenance

We suggested a controlling model for the maintenance process (Figure 6). The whole process of controlling and managing maintenance goes through a gradual algorithm of steps. The presumption of practical controlling function is evidence of material, spare parts, objects, equipment, machines, and instruments that are long-term property that needs to be maintained. The process of maintenance in the controlling module runs according to the following steps:

Damage note – it is reported that it classifies incidents on the equipment, for example, failure according to anticipated defined codes and catalogs. Order of maintenance – it presents a working command that is possible to follow, manage working activities on the equipment, plan activities on the equipment, and plan existing costs for equipment maintenance. The order should be linked to the technical place and the cost department. It states the annual plan for preventive maintenance – determination of demands timing norm and maintenance provider for concrete equipment. Comparing the plan with reality - in this module, we compared planned maintenance costs with existing costs. The total rate between corrective and preventive maintenance should be 20%: 80%, resulting from the RCM strategy.

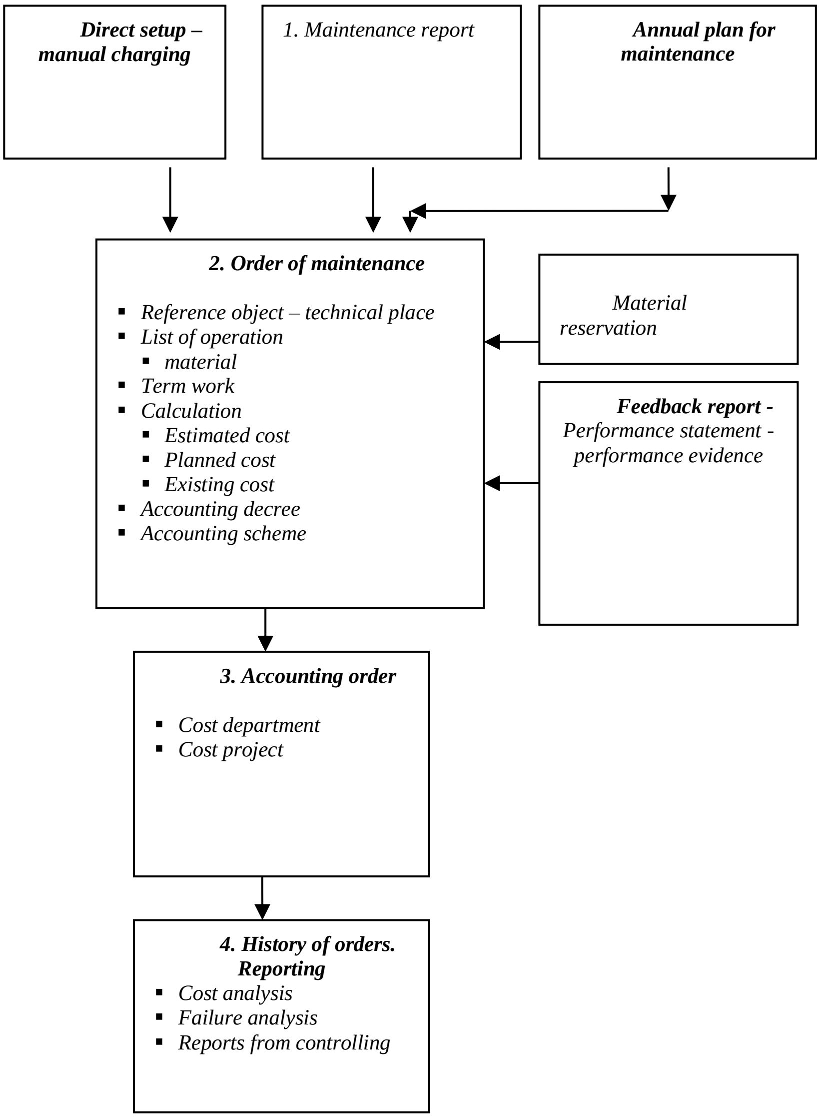

Fig. 6. Controlling model for the maintenance control process. Source: own source

Discussion

The economic analysis presented in the results section offers critical insights into the financial dynamics of maintenance costs, explicitly focusing on spare parts and other materials. The significant increase in spare part costs observed in 2020, followed by a notable decrease and a gradual upswing until 2022, suggests a complex interplay of factors potentially influenced by inflation and market dynamics. This cost fluctuation signifies the maintenance expenditures' sensitivity to external economic conditions. Moreover, the decrease in other material costs in 2021, juxtaposed with increases in 2019, 2020, and 2022, creates changes in maintenance budgeting in the financial area. The structural analysis reveals spare parts accounting for 10.6% to 39.7%, with a noteworthy increase in their share in 2019 leading to higher maintenance costs. Similarly, the structure for other materials, ranging from 13.5% to 31.2%, indicates a substantial contribution to the overall material costs, with a noticeable increase in 2022. As these cost dynamics directly influence maintenance work prices, a critical need arises to explore innovative cost optimization strategies within the maintenance process.

The introduction of a digital platform for spare parts registration, as illustrated in Figure 5, marks a key step toward increasing the efficiency and transparency of material management. This document encapsulates essential information for order management, including material details, specific codes, suppliers, plan numbers, dates, prices, quantities, and relevant logistics information. By digitizing this aspect of the maintenance workflow, the procurement process is streamlined and sets the foundation for more accurate cost tracking and strategic decision-making.

Furthermore, the suggested controlling model (Figure 6) provides a systematic framework for overseeing and managing the maintenance process. Anchored in a gradual algorithm of steps, this model is designed to control and manage maintenance activities for long-term assets. The structured process presents a holistic approach to maintenance management, starting with damage notes and extending to maintenance orders, annual plans for preventive maintenance, and a comparative analysis of planned versus actual costs. The model aligns with the Reliability-Centered Maintenance (RCM) strategy, aiming for a 20%:80% ratio between corrective and preventive maintenance, reinforcing the importance of a proactive approach to equipment upkeep. This controlling model facilitates effective incident classification and command-based management of activities and serves as a strategic tool for long-term planning, minimizing disruptions, and optimizing costs.

Teplická & Kádárová (2013) said that introducing Lean Management methodologies into the maintenance processes within the framework of establishing order and efficiency on the shop floor has proven to be an innovative and proactive approach. According to the results of research by Husar et al. (2023), it is evident that Lean Management principles, including 5S or Poka Yoke techniques, can be effectively applied beyond traditional manufacturing processes. In the context of maintenance, Lean Management brings about a systematic and organized approach to handling tasks, emphasizing continuous improvement and waste reduction. By incorporating the principles of 5S, we can create tailored solutions for streamlining activities. The methodical guidance provided by Lean Management principles ensures that maintenance tasks are carried out with precision and adherence to predefined steps. The adaptability and scalability of such systems enable easy integration into diverse maintenance scenarios, fostering a culture of efficiency and order.

By leveraging proven methodologies and adapting them to the specific context of maintenance, organizations can expect tangible improvements in task execution, reducing errors, and optimizing overall operational efficiency. Potkány et.al. (2012) said that the leveraging proven methodologies and adapting them to the specific context of maintenance, organizations can expect tangible improvements in task execution, reducing errors, and optimizing overall operational efficiency in the direction of calculation, budgeting, and competence management. Implementing a functional maintenance system affects the overall functioning of the business. The correlation between the functional state of machines and equipment and their performance is tied to the quality of products and services. Based on the analyzed parts of the research, we propose a maintenance system focused on Industry 4.0 (Figure 7).

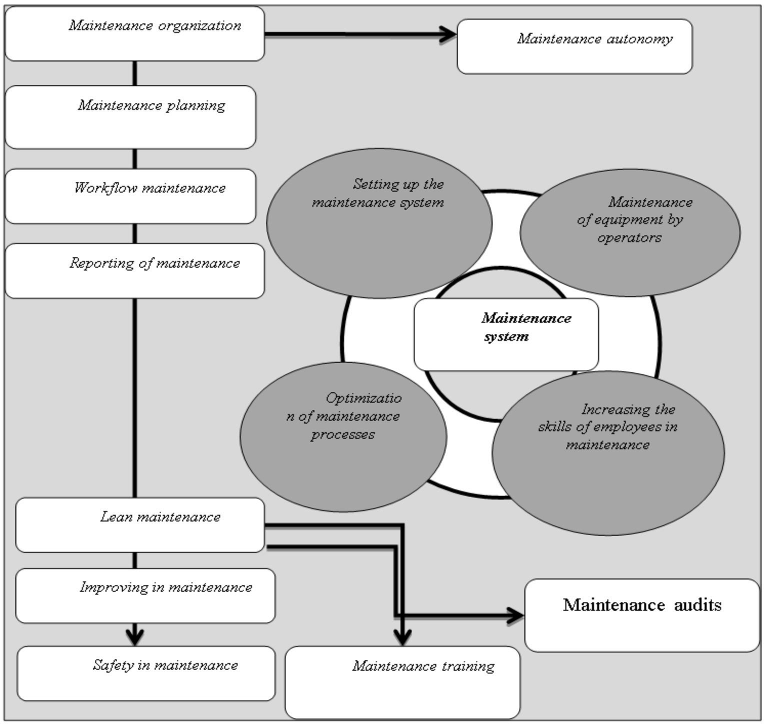

Fig. 7. Model of maintenance system according to Industry 4.0. Source: own source

Conclusions

The research methodology employed a combination of quantitative methods to address the maintenance process in the mining company. An analytical method was utilized for spare parts, offering insights into their availability and usage. The economical method facilitated the analysis of trends related to spare parts and other materials, ensuring a comprehensive understanding of resource utilization. Additionally, a graphical method was applied to optimize warehouse layout, and quality-flow charts were employed to enhance process visualization. A material evidence software application further supported the research, offering a digital framework for efficient record-keeping and management of spare parts.

This study focused on a mining company based in Slovakia that specializes in the maintenance of mining machines. By concentrating on this sector, the research aimed to address the specific challenges and requirements associated with the maintenance process in mining. The unique demands of maintaining heavy machinery in a dynamic mining environment provided valuable insights into tailoring an effective maintenance system that aligns with the principles of Industry 4.0.

This scientific investigation contributes to the ongoing discourse on maintenance process innovation, particularly in the context of Industry 4.0 requirements. The decision to focus on digitalization and optimization is both timely and critical for staying competitive in a rapidly evolving industrial landscape. The proposed document, spare parts record, supply flow chart, maintenance system model, and control model serve as tangible outcomes of the research, offering practical tools and recommendations for mining companies grappling with similar maintenance challenges. As industries transition towards a more digitally integrated future, embracing innovation in maintenance becomes imperative for sustained efficiency and operational excellence. The maintenance process is a supporting process in the IPO chain and cannot be canceled because all business processes are in synergy. The research aimed to point out the possibilities of optimizing the maintenance process in mining companies and to focus on problems related to the low use of maintenance workers' working time, troubleshooting, and lack of workers for preventive maintenance. Non-fulfillment of the preventive maintenance plan and technical deficiencies are reflected in the financial area. Those barriers create high costs that need to be minimized. By making changes in the maintenance process, we pointed to the pillars of the industrial era Industry 4.0, the purpose of which is optimization and digitization.

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