

# Strategic Management Plan for Maintenance in Mining Companies as a Form of Technological Innovation

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**Abstracts:** This paper presents a proposal for a strategic management plan to optimize the maintenance system of mining companies. In the first phase of this investigation, the potential failures and their possible consequences for the machinery, the administrative area, the warehouse, and computing hardware were identified to determine the most critical components and thus propose a strategic maintenance plan that includes preventive actions for each of the areas concerned. The data for this research were collected through a bibliographic review, direct observation, surveys, and interviews. Standardized tools and techniques such as criticality analysis, the balanced scorecard, and SWOT matrices were used. The research is of a projective type, with a non-experimental field design. The action plan includes the strategies necessary to close the gap between the current state and the desired optimum level. It establishes the impact that applying the proposed improvement plan for maintenance management will have on companies in the mining sector, both in terms of productivity and competitiveness. In conclusion, for mining companies to have strategic planning for equipment and infrastructure maintenance that will allow them to improve their productivity, sustainability, and competitiveness, they must have a strategic plan developed in situ, which includes as many variables as possible, trying to cover all the common elements that will allow this strategy to be applied in mining companies both regionally and globally.

**Keywords:** Improvement proposal, Strategic maintenance planning, Maintenance variables, Competitiveness, Mining sector.

## 1. INTRODUCTION

Globalization and competitiveness are well-known terms associated with development due to technological progress. This connection also applies to the mining industry. The ability of mining companies to develop and implement innovative approaches in strategic planning and asset management will be critical to meeting the demands of competitiveness and ensuring their sustainable operation and development. Corporate strategic planning refers to an overall long-term plan for an organization that includes the vision, mission, values, business policies, objectives, and risk management (Komljenovic, 2015).

Professional experience in the mining industry has shown that the knowledge achieved at one mining site does not always work well or can be applied in other mines of different minerals. That is due to local conditions: norms, culture, and available resources that can vary substantially from site to site (Carter, 2015). In addition, most major mining equipment is mobile and adds to increased complexity in mining operations. In addition, mining companies also operate in complex scenarios involving the business, natural, technical, technological, organizational, regulatory, legal, political, financial and market environments, which are defined by significant intrinsic uncertainties (Komljenovic, 2007).

The mining industry is quite sensitive to several extreme changes: unexpected natural or mankind-made events. A review of the literature infers that there is not much research in this field, which would help to understand the impact of strategic planning and asset management in the mining sector. Mining companies are complex because of their organization, managerial and operational structure, which adds to the overall complexity and uncertainties. Mining companies operate in a complex, dynamic, and rarely predictable business and operating environment.

The management and strategic planning of maintenance in mining processes are essential to guarantee the long-term success of any maintenance program through the control of quality assurance, operational efficiency, and assets for optimal operation. Properly maintained assets keep your production stable and indeed reduce the chances of unplanned downtime. The latter causes a snowball effect that implies an increase in unexpected costs in repairs, overtime, spare parts, shipment delays, lost income, or serious machinery failures.

Within the organizational structure of the mining company, the maintenance area is responsible for ensuring the operational availability of the company's mobile industrial equipment by performing preventive, corrective, scheduled, and routine maintenance. The company under study does not have a maintenance management system that guarantees the effective and efficient use of material, economic, human, and time resources to ensure the maintenance objectives. For this reason, it is necessary to guarantee that the equipment is in optimal conditions. Achieving this is required good programming and execution by the operations and maintenance team.

To provide a background for the research, Wang et al. (2007) analyzed several maintenance strategies for diverse equipment and modified the analytical process hierarchy by transforming uncertain and imprecise judgments of decision-makers into fuzzy variables. In the research of Pourjavad et al. (2013), a proposed novel periodicity metric combined with other performance metrics such as cost, availability, and product quality, can improve decision-making in the proper selection of maintenance strategies. On the other hand, Jafari et al. (2008) suggested a novel approach that can determine the most appropriate maintenance strategy considering the level of uncertainty and variety of maintenance criteria.

Sachdeva et al. (2008) proposed an approach to formulate an efficient and effective priority ranking system of the various components, or failure modes, for many maintenance problems based on failure modes and effects analysis and process analytic hierarchy techniques. For a category of equipment in a mining company, Melechy et al. (2010) proposed a method that comprises comparing five maintenance strategies based on a variety of criteria such as cost, maintainability, availability, and reliability. These strategies were ranked from 1 to 5 for each category of equipment.

Komljenovic et al. (2015) present a new approach to strategic planning and asset management for Mining companies, analyzing the problem by applying complex adaptive systems. Shahin et al. (2012) sought to identify the most appropriate maintenance strategies to suit a category or type of equipment in a Mining company. The results they obtained highlight the priorities of maintenance strategies and that maintainability and reliability are the main reasons for the rankings and priors of these strategies.

Núñez et al. (2020) presented the basis for the design of a competitiveness management system for medium and small industries and providers of operation and maintenance services to the mining sector, concluding that they are not in line with the requirements of the competitiveness management processes and that there are weaknesses that should strengthen taking into account the recommendations for the design of the management system as well as for the strategic direction.

Equipment maintenance impacts strongly over the operability of a mining company's machinery and equipment. Therefore, maintenance strategies represent a distinct subtopic in the operations management Field (Gebauer et al., 2008). According to Simoes et al. (2011), strategic maintenance management is essential for making the best decisions. The importance of selecting an appropriate maintenance strategy is different for each company.

Gamboa (2009) presented a Proposal of Organizational Bases of the Maintenance Function for a Welding Workshop. The study considered aspects related to planning, prioritization, scheduling, execution, and measurement used in the areas evaluated according to the above proposal, adding a series of additional recommendations to guarantee the optimal operation of the workshop assets. On the other hand, Reyes (2009) proposed a maintenance management improvement plan for manufacturing companies and suppliers of the oil industry, through the fundamental and critical parameters of the processes involved in the productive sector and the integral maintenance system, based on the various perspectives of detailed maintenance.

On the other hand, Vasquez (2011) formulated a Methodology for Auditing Maintenance Management. This methodology proposed the vision of designing a management tool to determine the management, maturity degree, and identify areas of potential improvement of the maintenance organization, allowing management to make decisions that lead to optimized decision making.

Maintenance costs represent a significant part of total operating costs. Usually, a large percentage of the mine's entire workforce is spent on servicing and repairing machinery in the field. Strategic maintenance management and planning in mining companies are necessary to ensure long-term success and optimal operation of any maintenance strategy. This work proposes, from the particular to the general, to improve the management plan for the strategic maintenance of a company engaged in mining activities:

- i) Diagnose in situ the current state of the maintenance plan of a mining company.
- ii) Based on this, propose changes, updates, and adjustments that will allow improving the mining company's maintenance management plan.

The current state of the mining company is analyzed using standardized data collection techniques, and using the information obtained, optimization of the maintenance plan is proposed by incorporating Industry 4.0 elements. The impact that the implementation of the proposed program will have on companies in the mining sector in terms of productivity, sustainability, and competitiveness as a form of technological innovation will be identified. The research was developed at the company's location, which led to reliable results adapted to reality. The work establishes the necessary elements to build a strategic maintenance management plan that could be applied to any mining company.

In this paper, the following structure is followed: section II corresponds to the development of the problem, where the case study is delimited according to the theoretical bases that support it. Additionally, the methodology used during the research is specified. Section III shows the main results obtained, and then, in section IV, the results achieved are discussed. And finally, the conclusions on the research topic are presented.

## **2. DEVELOPMENT**

The company selected for the study participates in the engineering solutions for the different stages of the iron ore processes, from its exploitation, processing, and profiling, to its handling and transportation. Services offered are inspections, sampling, profiling, and transportation of raw materials.

To carry out different machinery activities and equipment must be maintained according to schedule, following the technical manuals, to maintain their functionality and avoid process interruptions due to mechanical or electrical failures. It is important to emphasize that a maintenance management plan is required to maintain the operation of the machinery and equipment. In this sense, strategic maintenance planning allows managing and channeling the material and human resources available in the companies to ensure that the machinery and equipment perform their functions and their operation is reliable in the mining process.

Strategic planning systematizes processes and ensures that the tasks necessary to achieve the company's goal in its operational context take place. Strategic planning for maintenance preserves operability, optimizes performance, and increases the useful life of assets by seeking optimal investment of resources (Komljenovic et al., 2015).

### **2. 1. Maintenance Organization**

Depending on the maintenance workload, and the worker skills, among other aspects, maintenance can be organized by department, by area, or centrally. The creation of several units reduces the flexibility of the maintenance system. The workforce and its availability are lower compared to a centralized maintenance unit. All

this leads to the need to improve strategic planning and establish an innovative proposal for the mining sector, adapted to new trends, such as Industry 4.0 (Robles et al., 2020).

Maintenance planning is a procedure to allocate resources and personnel for maintenance activities to realize at a given time. Maintenance schedules must consider critical equipment because a failure of this equipment will stop the production process or put the safety of workers at risk. In the mining area, the occurrence of unexpected events is frequent. Therefore, the maintenance programs must be reviewed and contemplate these cases. The efficiency of a maintenance program will depend on its flexibility to adjust to changes.

Due to globalization, companies must constantly improve and effectively manage their operations. The mining company under study has not carried out a systematized and detailed analysis of its external and internal environment; therefore, the company is unaware of important aspects that limit its growth and survival in the long term. For this reason, a strategic plan for a maintenance company in the mining sector is developed on site.

Planning a maintenance system consists of:

- a) Work design: includes the activities for each task and determines the method to be used, the tools needed, and the workers required.
- b) Standardized time measurements: the time it takes to complete an activity must be estimated. Time measurements are an essential element for increasing work efficiency. It is not crucial to have a time standard for all maintenance jobs, only for those that are critical, time consuming or impede the continuity of the process.
- c) Project management: preventive maintenance is accomplished regularly. During these activities, part of the process is interrupted. Therefore, it is necessary to plan the work to ensure the optimal use of resources.

## **2.2. Maintenance Parameters**

According to Zambrano and Leal (2007), to ensure a good performance of the equipment functions, it is necessary to measure in a simple way its essential characteristics through the following parameters:

**Reliability:** is the probability that an asset or system will operate under normal conditions for a set time. The parameter that identifies reliability is the Mean Time to Failure, which is the time that elapses between failures.

**Maintainability:** is the probability of an asset or system repairing during an established time under established procedural conditions, its main parameter being the Average Downtime.

**Availability:** refers to the set time to an asset or system remains functional within the production system under certain conditions. This parameter is perhaps the most important within a production system since the planning of the rest of the organization's activities depends on it.

## **2.3. Maintenance Strategic Planning**

It is necessary to properly manage the needs and priorities of the maintenance function to achieve operational success. Maintenance management is the effective and efficient use of material, economic, human, and time resources to achieve maintenance objectives. Due to market demands, there is currently a transition phase in which excellence is considered part of the product. Therefore, companies are facing the question of how to improve their maintenance management to become more sustainable. That is where strategic planning comes in to create a competitive framework.

## **2.4. Maintenance Management Phases**

López (2017) states that in maintenance management, planning and scheduling represent the starting point and involve the need to imagine and relate the probable activities that must be complied with to achieve the objectives and expected results. Each of the stages of maintenance management follows a description:

- Planning: consists of defining routines and procedures and preparing detailed plans for long terms, usually quarterly or annually, which involves determining the necessary operations, labor required, materials to be used, equipment to be used, and duration of activities. Maintenance planning should consider the following aspects:
  - Maintenance planning should consider the following aspects:
  - Have established objectives and goals for the equipment to be maintained.
  - Guarantee the availability of the equipment or systems.
  - Establish an order of priorities for the execution of maintenance actions.
  - Logical signaling and coding system.
  - Inventory.
  - Maintenance procedures and routines.
  - Records of failures and causes.
  - Downtime and repair time statistics.
- Scheduling: consists of establishing the frequency of preventive maintenance assignments. Scheduled dates are essential for the continuous availability of equipment and facilities.
- Execution, control, and evaluation: connect two administrative actions such as the direction and coordination of the efforts of the group involved in the planning and programming activities whose purpose is to guarantee the achievement of the proposed objectives. Execution, control, and evaluation: link two administrative actions such as the direction and coordination of the efforts of the group involved in the planning and programming activities whose purpose is to guarantee the achievement of the proposed objectives.

## **2.5. SWOT Analysis**

The SWOT matrix (Carreto, 2007) is a diagnostic tool that leads to the development of four types of strategies. Talancón (2007) explains that a SWOT analysis consists of an assessment of the strengths and weaknesses factors that, taken together, diagnose the internal situation of an organization as well as its external evaluation, i.e., opportunities and threats. It is a simple tool that provides an overview of the strategic position of a particular organization.

## **2.6. Criticality Analysis**

Huerta (2001) defines it as a methodology that allows systems, facilities, and equipment to be hierarchized according to their global impact to facilitate decision-making. Criticality analysis allows to development of a strategy to serve as a tool to determine the hierarchy of processes, systems, and equipment in a complex facility and to allow the subdivision of the elements into manageable sections in a controlled and verifiable manner.

## **2.7. Technology Innovation Indicators**

- Investment in technological innovations: Software, processes, machinery.
- Strategic use of information: Computer equipment, internet, information systems, human resources, inventory control, suppliers.
- Technological capacity: useful life of machines, software, certification of equipment.
- Proprietary technologies, process, and management innovation measures, planning.

## **2.8. Methodology**

The first step was to assess the current situation of a mining company concerning its maintenance management. Luego se proponen estrategias para mejorar la planificación estratégica de la gestión. Por lo tanto, la investigación es de tipo proyectiva y fue orientada hacia un diseño de campo. The proposed study is consistent with the goals of nonexperimental research, where no hypotheses are proposed, but rather a set of study variables. It means that the way in which the events associated with the problem occur and how they are related to each other has been studied.

In developing this research, in addition to direct observation, data was collected directly on the scene by interviewing subjects in their daily environment and then analyzing and interpreting the results of these activities. The object of study is a finite population represented and delimited by the totality of the machinery and equipment of a mining company, whose main task is to operate and maintain the loading equipment belonging to the company.

Due to the characteristics of this study, a group of equipment selected according to the following criteria and in line with the strategy proposed in the research:

1. All equipment has been in operation for more than one year.
2. Basic personnel involved in maintenance: supervisors and executors of the maintenance activities.
3. Executive management personnel, middle management, and coordinators of the maintenance department and logistical support and resources department.

It was necessary to observe and participate directly in the field to be in contact with the strategic and operational parts of the company, to evaluate and diagnose the current situation, and thus define the strategies for the action plan.

The survey allowed the collection of information and data that contributes to evaluate of the company's current context. Interviews were conducted with coordinators, supervisors, performers of maintenance activities, logistical support, and management personnel. It focused on their views of current maintenance management, discussing the strengths and weaknesses of the current model and including external factors that influence the maintenance system and are outside the direct control of supervisors. This information supplemented the data obtained through the survey and direct observation.

The standard (CVNI, 1993) was used to evaluate maintenance systems in the Mining industry and was applied to comparing and evaluating the company's current maintenance management system. A bibliographic review was performed using books, company documents, dissertations, manufacturer catalogs, and scientific publications. Therefore, the theoretical-practical foundations were established, which served as a frame of reference and support for this research.

### **2.8.1. Data Analysis Techniques**

A criticality analysis helped to classify critical systems, facilities, and equipment to facilitate decision-making. Also, a failure analysis was performed to investigate critical equipment failures. A failure mode (how they occur) and failure effects analysis was also conducted to examine critical equipment failures, the detailed operation of each component, the failure modes or failures causes, and the effects caused by those failures. The balanced scorecard is an accurate and comprehensive approach to developing and implementing an asset management strategy. It relies on performance measurement, using management indicators or metrics for strategy development and implementation.

### **2.8.2. Procedure**

A diagnosis of the current maintenance situation in the area of material transport of the mining company was made based on:

- Review of documentation for equipment operation.
- Visualization of maintenance programs currently being performed.
- Conduct interviews with personnel responsible for maintenance.
- Assessing the operational status of the equipment using maintenance indicators.

We then proceeded to collect and analyze the data and develop an assessment or diagnosis of maintenance to identify the potential weaknesses in maintenance management. It used the weighting resulting from the survey compared to the expected weighting of an optimal maintenance management system established by the previously mentioned standards.

Using the tool SWOT, strengths, opportunities, weaknesses, and threats of the current maintenance management system were identified, and an action plan for improvement was proposed to reduce the gaps in maintenance management according to the standards. This action plan helped to identify and prioritize possible actions to correct the main deficiencies. In addition, it will provide the area with a guide for the organization of the aspects to be improved, allowing the control and monitoring of the different actions to be developed (Pourjavad, 2015). After proposing the measures and strategies to improve the management system, the impact of this optimization was determined. Finally, adapting and upgrading machinery, software and equipment to enable the Mining company to be part of Industry 4.0 is a proposed form of technological innovation (Robles et al., 2020).

## **3. RESULTS**

It evaluated the current situation of the maintenance management system in the material handling area of a mining company, using the standard (CVN, 1993) as the basis for the assessment. The diagnostic results were used to identify a gap between the current state and potential improvements and to determine the actions and strategies to be implemented for strategic maintenance planning.

### **3.1. Assessment of the Current Maintenance Management System**

It used a questionnaire for the assessment to make the best use of the quantitative data for the analysis. The standard (CVN, 1993) includes twelve areas to be assessed, covering the most relevant aspects: Business Organization, Maintenance Organization, Maintenance Planning, Routine Maintenance, Scheduled Maintenance, Circumstantial, Corrective, Preventive Maintenance, Failure, Maintenance Personnel, Logistical Support, and Resources. The assessment results of only three areas are presented below as examples.

### a) Company Organization

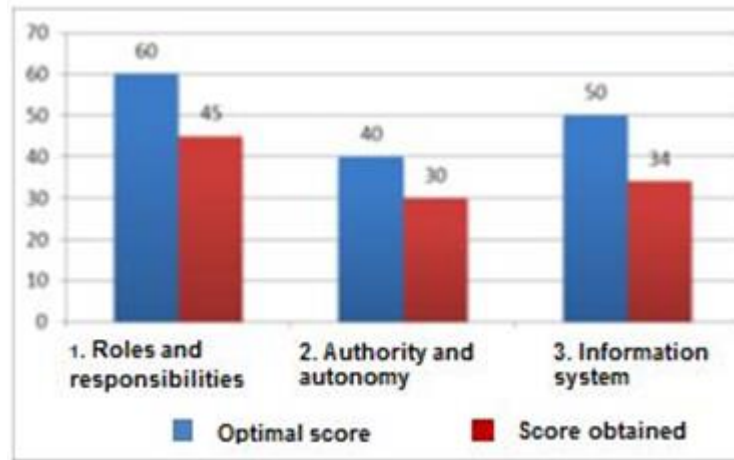


Figure 1. Diagnosis Results in the Company's Organization Area.

Figure 1 shows that, of a total of 150 points, the mining company achieved 109 (73%), which shows that the roles and assignment of responsibilities were not completely clear. Therefore, there are opportunities for improvement in the company's information system. The standard indicates that the company must have a technical-administrative structure for collecting, purging, and storing information.

### b) Maintenance organization area

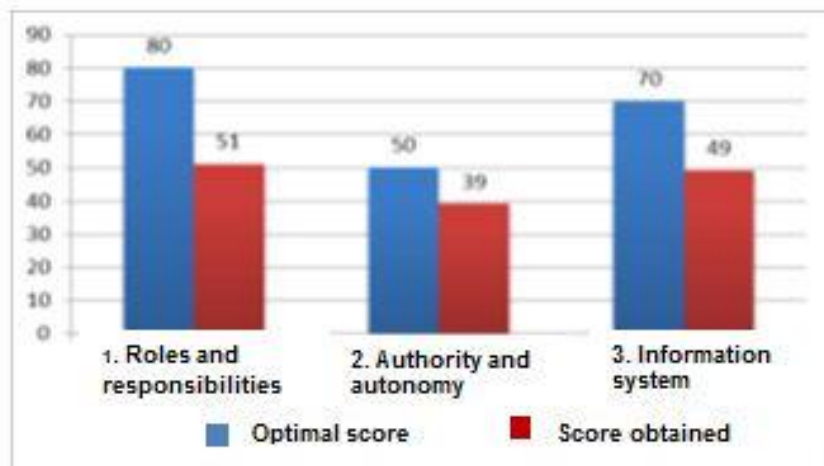


Figure 2. Result of the Diagnosis in the Maintenance Organization area.

As shown in Figure 2, the company obtained 139 points (70%) out of 200. according to these statistics, the company's material handling and hauling area do not have sufficient personnel to cover maintenance needs, and the consequence is overlapping or duplicated functions. The information system does not have a system that allows it to optimally manage all the maintenance information (failure records, maintenance planning, statistics, costs, equipment information).



c) Maintenance planning area

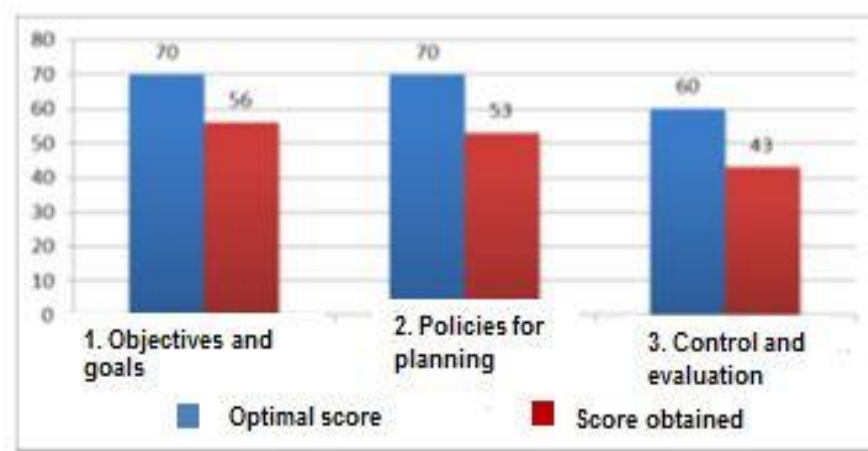


Figure 3. Diagnostic Results in the area of Maintenance Planning.

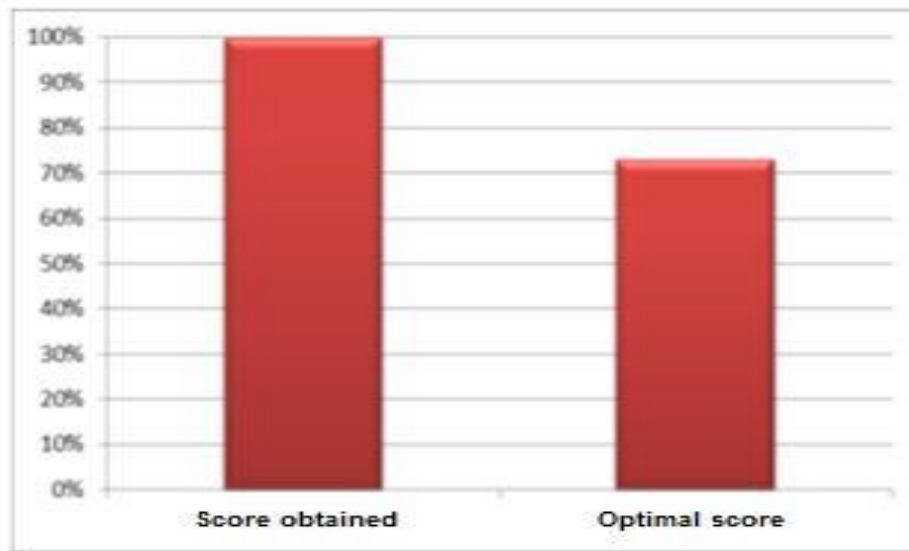
The company achieved a score of 76% in this area, as shown in Figure 3. In addition, the company has goals and objectives for maintenance, and the priorities of critical maintenance units are well established. However, maintenance plans are inadequate, resulting in corrective maintenance being used for failures in most cases. The principle of control and evaluation can be improved by written records of issues and their causes. Statistics on issues and repair times are also needed, as this information must be processed and analyzed for future decision making.

Table 1 shows the results obtained in the evaluation applied to the twelve areas, as established in the standard, which allows visualizing the percentage weightings obtained by each area evaluated, thus being able to identify which are the most problematic and which are affected by inadequate maintenance management.

Table 1. Summary by Maintenance Management System Assessment Area.

Maintenance types	Score according to standard	Score Obtained	%
Company Organization	150	109	73
Maintenance Organization	200	139	70
Maintenance Planning	200	152	76
Routine Maintenance	250	186	74
Scheduled Maintenance	250	176	70
Circumstantial Maintenance	250	186	74
Corrective Maintenance	250	198	79
Preventive Maintenance	250	188	75
Breakdown Maintenance	250	196	78
Maintenance Personnel	200	137	69
Logistical Support	100	75	75
Resources	150	81	54

In addition, it allows observing the total score obtained in the maintenance management diagnosis of the Materials Handling and Hauling area, as shown in Figure 4 score obtained through the evaluation was 73%.



**Figure 4.** The diagnosis allows determining the overall percentage obtained in the evaluation.

Figure 4 shows that the score obtained is 73%, which shows that the current maintenance management system is in a normal situation, evidencing the existence of elemental maintenance management.

### 3.2. Current Situation Assessment of Maintenance Management by Means of SWOT

An analysis was made by combining the interior of the current management system (Strengths and Weaknesses) with the external factors (Opportunities and Threats) to establish the strategies and actions to be carried out as an action plan to adapt and solve the problems.

### 3.3. Internal and External Media Analysis

In the analysis of the internal environment, the internal aspects of the maintenance unit were recognized. It covers the strengths or positive aspects and the weaknesses or aspects to be improved of the unit. By studying the positive and negative influences for the current Maintenance Management System coming from the external environment, the opportunities and threats that allow the mining company to be prepared for possible events are defined. Table 2 shows the SWOT Matrix of the Materials Handling and Hauling area, considering the internal elements described above. Table 3 shows the SWOT Matrix, considering the external elements.

**Table 2.** Internal Situation Corresponding to the Strengths and Weaknesses of the Maintenance Management of a Mining Company.

Internal Situation	
Strengths	Weaknesses
<ul style="list-style-type: none"> <li>• There are controls on the use and condition of the equipment.</li> <li>• There are procedures for personnel selection, training, and development.</li> <li>• There are manuals of job descriptions, functions, and responsibilities.</li> <li>• All mechanical and electrical components of the equipment are registered.</li> <li>• Equipment is coded.</li> <li>• The necessary resources are available to carry out preventive maintenance activities.</li> <li>• The safety program for accident prevention is based on compliance with the technical standards of the law.</li> <li>• Trained and experienced personnel (technical and administrative) capable of resolving, at all times, any</li> </ul>	<ul style="list-style-type: none"> <li>• Deficient preventive maintenance plans lead to corrective maintenance when a failure occurs.</li> <li>• There is a lack of personnel for collecting, purging, storing, processing, and distributing information derived from failures.</li> <li>• Lack of identification of materials and spare parts in the warehouse area.</li> <li>• Lack of control forms for incoming and outgoing materials in permanent circulation.</li> <li>• Lack of inventory management software.</li> <li>• The warehouse area is not equipped with all materials and spare parts.</li> <li>• There are no defined procedures to calculate equipment reliability and maintainability indicators and to stipulate the frequency of revision and replacement of critical parts</li> </ul>

<p>problems that may arise within the maintenance plan.</p> <ul style="list-style-type: none"> <li>• There are warehouses to store materials, spare parts, and tools.</li> </ul>	<p>in the equipment to be maintained.</p> <ul style="list-style-type: none"> <li>• Staff busy or unavailability of spare parts when maintenance activities must be performed.</li> <li>• Maintenance personnel experience shortages of materials and supplies such as oil or grease and few spare parts for heavy machines.</li> <li>• Lack of a system or software to manage information more efficiently.</li> <li>• Manuals and catalogs for all machines are not available.</li> <li>• Many procedures must be carried out within the company to obtain the necessary resources for maintenance management.</li> </ul>
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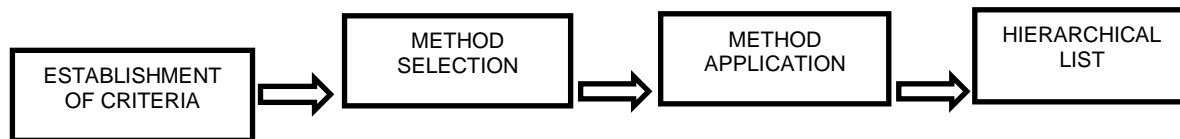
**Table 3.** The Internal Situation Regarding the Strengths and Weaknesses in the Maintenance Management of a Mining Company.

External Environment	
Opportunities	Menaces
<ul style="list-style-type: none"> <li>• Economic solvency of the buyers.</li> <li>• Large national and international market.</li> <li>• Refresher courses for workers to train them in the different maintenance types and their strategies.</li> <li>• Implementation of a computerized system for the management of maintenance information.</li> <li>• International suppliers have the necessary machinery and support units to support the production process.</li> <li>• Suppliers that have all the spare parts and materials for equipment necessary to carry out maintenance activities.</li> <li>• Adoption of continuous improvement policies by the company in general.</li> <li>• Current trends in maintenance management.</li> <li>• Company with the economic capacity that makes possible the training of its labor force in all types of techniques necessary to improve the performance of its maintenance tasks.</li> </ul>	<ul style="list-style-type: none"> <li>• Workers unwilling to receive training courses</li> <li>• Resistance to the adoption of new methodologies.</li> <li>• The current world economic crisis generates low demand for goods and services.</li> <li>• Currency adjustment affects the price of equipment and products at the time of importation.</li> <li>• Delivery time of spare parts.</li> <li>• High costs of equipment repairs that need outside repair shops.</li> </ul>

Once the SWOT matrix, which shows the internal and external factors that influence the area's performance, had been prepared, an evaluation of the area's internal situation took place using the internal factors evaluation matrix.

### 3.4. Equipment Criticality

The objective of this methodology is to determine which equipment is considered critical for the correct operation of the material handling and hauling area, resulting in the requirement to establish efficient preventive maintenance tasks that will allow avoiding the possible causes of failure of such equipment.



**Figure 5.** Basic Criticality Model.

Based on the criteria shown in Figure 5, the criticality of the equipment was evaluated according to a weighting and a score for each situation within each criterion. The criticality analysis allowed information collection from supervisors, maintainers, and operators. Once the information is collected, the criticality value of the equipment is obtained by averaging the results of each work team member. It is done for the equipment and the machinery in the area studied. The results of the criticality of the teams made it possible to classify them according to their use and establish maintenance priorities. Therefore, the gap between the current situation and what is to be achieved, according to the regulations, is determined. In this way, the strategies to be implemented to move towards the optimized maintenance management model are established. The criticality analysis was carried out based on the following factors: failure frequency, operational impact, the average time to repair, impact on production, operational

flexibility, maintenance cost, safety impact, and environmental impact. That made it possible to classify the equipment from most critical to least critical.

### **3.5. Improvement Action Plan to Optimize the Maintenance Management Plan**

Below is the action plan to increase the efficiency and effectiveness of the system. The action plan is structured such that the activities are organized into five groups to simplify the study. The general action plan is detailed below, which establishes:

- 1) The strategies that will allow increasing the effectiveness of strategic maintenance.
- 2) The actions that will make it possible to comply with the established strategies.
- 3) The necessary resources to develop the proposed activities.
- 4) The time of execution of each activity and,
- 5) Those responsible for the execution.

### **3.6. Variables and Action Program for the Maintenance Plan**

The variables and factors considered for the action program are as follows:

**Strategies:** Evaluate and select suppliers, establish inventory policies, and implement rules for organizational development. Train and educate personnel, and consider the cost structure of the area. Implement strategic maintenance planning taking into account management indicators. That implies the implementation of computer systems with updated software to streamline maintenance management and preventive maintenance equipment, with scheduled shutdowns in a reasonable time according to the standard.

**Activities:** Quality control of spare parts, delivery times, and warranties. Inventory level and monitoring. Talks to managers and workers in general. Detection of real maintenance needs and distribution of tasks according to the operators' responsibility and specialization. Training and updating of personnel to improve their knowledge. Efficient management of resources. Recording of damages and maintenance performed on each piece of equipment. Time, spare parts used, costs, and labor hours spent.

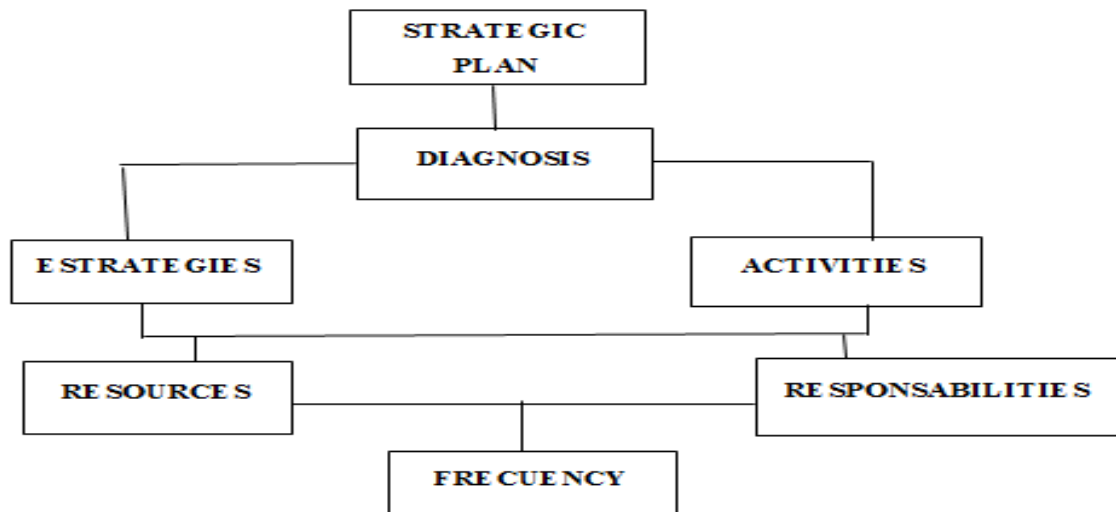
**Systemization and Automation:** As a form of technological innovation, process automation, use of software appropriate to the area, and recording failure modes and effects. Scheduled maintenance of equipment and machinery. Analysis of the proposed tasks identifying the required resources, labor, and spare parts. Inventory control through software.

**Resources:** Public bidding when warranted. Inventories, codifications, and manuals. Failure analysis, failure records, budgets. Work orders, procedure manuals.

**Frequency:** Monthly, quarterly, semi-annually, or annually depending on maintenance manuals and equipment characteristics.

**Responsible:** Maintenance chiefs, maintenance coordinators, and the head of human resources.

At this level, the proposal for the improvement of the strategic maintenance plan (Figure 6) and thus determine the most appropriate maintenance strategy in a mining company dedicated to the handling and hauling of materials involves:



**Figure 6.** Summary of the Strategic Maintenance Plan, Ranking the Variables by the Level of Importance.

The proposed plan inherently involves the following activities:

1. Comparison of levels, diagnosing the current state of innovation levels in management, equipment, and machinery based on parameters such as systematization and automation of procedures and processes, time of use, previous maintenance, frequency of use, strategy, and frequency of each piece of equipment.
2. SWOT matrix and criticality analysis (internal and external analysis).
3. According to the detected, optimize the maintenance management plan.
4. Establish maintenance strategies according to costs, maintainability, availability, reliability, and frequency for an equipment category of the mining company.
5. Procedures automatization, activities, and processes (Robles et al., 2022).
6. Adaptation to the laws and regulations that regulate the mining activity.
7. Implementation and impact of the action plan.
8. Costs, advantages, testing, and validation.

Technological innovation is essential to meet the challenges of Industry 4.0 in the mining sector. The industry needs to promote innovation to make mineral extraction and processing processes more efficient, which impacts productivity and competitiveness. The digitization of mining companies is imminent, which will help increase the efficiency and performance of operations and force personnel to train and acquire new skills. The trend in the industrial sector worldwide is to try to make processes autonomous.

The strategic maintenance plan proposed in this work can bring tangible benefits to mining companies, such as the following:

- Having a robust and integrated strategic management planning system with a rigorous scientific-technical basis. It also provides new knowledge for a better understanding of the operating environment of mining companies in strategic maintenance planning.

- It introduces the automation of some activities as a form of technological innovation, which also has positive socio-economic and environmental implications, which will lead to the placement of telecommunications services in all areas to digitize, integrate, automate and control the mining process.
- Increases mining organizations' robustness, resilience, and flexibility in the face of diverse and uncertain scenarios and unforeseen events.
- Optimizes return on investment and business growth.
- -Enables long-term planning and supports the sustainability of company performance through more realistic models.

### 3.7. Impact of the Improvement of the Maintenance Management System

At this level, the impact that the implementation of the Maintenance Management System improvement project would have on the mining company is evaluated (Table 4). That allows verifying that the proposal makes operational sense and that the mining company will have in med-term an experienced team of professionals will help the mining operations reach their highest potentials to improve productivity and sustainability.

**Table 4.** Impact of Maintenance Management System Improvement.

Strategies	Impact
Evaluate and select suppliers based on cost structure and best value for money.	Negotiate cost-effective budgets for the company with purchase and sale agreements.
	Acquisition of imported equipment, parts, and materials adjusted to inflationary levels.
	Decrease in the time it takes to perform maintenance activities.
Establish inventory policies through the use of the software.	Avoid or reduce delays in the execution of maintenance due to waiting for material or spare parts. Improve the operational availability of equipment.
Adopt policies for organizational development through the strategic plan.	It will allow adapting the organizational structure (organization chart), following efficient conduction of the work groups (teams and leadership) to prevent delays in the maintenance actions.
Train and educate personnel in operability, technical area, and risk management plan.	To have workers with quality and labor efficiency.
	Boost Talent, knowledge, and motivation of the personnel.
	Sensitizes the equipment's personnel to create a culture of care and maintenance.
Evaluate the economic position of the area considering the cost structure.	It allows to achieve a budget adjusted to the needs of the area. It also achieves the updating and replacement of machinery and equipment according to plan.
Encourage personnel through productivity bonuses and fewer accidents.	To have workers with higher performance and better performance.
Implement maintenance management indicators.	Enable the detection of processes in the area where management problems exist.
Provide updated computer systems for inventory control for inventory control, input and output of materials, and automation of processes and machinery within Industry 4.0.	Strengthen the tool for collecting and processing information.
	Update the company's information system to organize procedures and systematize processes in accordance with Industry 4.0.
	Improve the processing and distribution of information regarding the maintenance of the company's mobile equipment.
Implement maintenance management indicators.	Improve the technical and operational status of the equipment.
	Reduce the risk of equipment breakdowns.
	Schedule preventive works.
	Perform repairs in conditions favorable to the operation.
	Reduce costs. Prolong equipment lifetime.

## 4. DISCUSSION

The needs most highlighted in the diagnosis and which influence the competitive strengthening of mining companies have to do with their strategic direction. Then there are those associated with the structure of standardized processes, the appropriate technology, and the adequate management of suppliers to ensure the quality of inputs, machinery, and equipment required to provide services.

It was used in the consultations with the maintenance personnel because there is no history of equipment failures and, in addition, the area of material handling and hauling is relatively new. The elaboration of the failure modes and effects of the equipment under study made it possible to establish the appropriate maintenance frequencies and activities to reduce corrective actions and increase the reliability of the equipment.

The action plan proposed defined the strategies, activities, resources, time, and responsibilities, considering the organizational elements, planning, scheduling, and control of maintenance and resources (human, financial, and material). Finally, It made an impact analysis on the company's maintenance area of implementing the actions and strategies proposed as improvements to optimize the maintenance management system. The activities to be followed were established as well as the results to be obtained.

The environment of a mining company is unpredictable and dynamic. Standardization processes within a mining operation can provide stability, consistency, and predictability. One factor that has encouraged implementation management and strategic planning systems for machinery and equipment maintenance is the possibility of having a competitive advantage in bidding processes since one of the requirements to aspire are to be certified with some quality standard.

## 5. CONCLUSIONS

This work, carried out with data in situ, concludes that mining companies must keep pace with innovations in strategic planning processes in maintenance to improve their productivity and competitiveness. That leads to set strategies through a maintenance management plan that considers numerous variables, trying to cover common elements and applied on a regional and global scale in companies extracting different minerals.

The environment of a mining company is unpredictable and dynamic. Standardization, process improvements, and optimization of the maintenance management plan offer stability, consistency, and predictability for productivity improvement. One of the factors that have encouraged the implementation of management systems and strategic planning for maintenance is the possibility of having a competitive advantage at a global level.

Mining companies face stiff global competition that constantly drives them to produce more at a lower cost. They also face a very complex situation in their commercial and business-related operating environment, with technological, organizational, regulatory, legal, financial, and environmental factors. Strategic planning as a form of technological innovation plays a fundamental role in this environment, automating procedures that will lead to digitizing, integrating, automating, and controlling the mining process.

This work places the mining company studied at the forefront by adopting an optimization tool based on on-site experiences. The need to evaluate maintenance processes that are adequate to each country or region's standards will impact their improvement, leading the organization to implement its strategic management plan to compete with other companies in the area (Fuentes, 2017). That is why the maintenance management proposal was made to effectively control maintenance compliance, improve the area's performance, increase the operational performance of the equipment, its useful life, and guarantee its availability.

**Future Work:** This work should be extended to study which activities and procedures a mining company can automate in the Industry 4.0 context.

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