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Implementing Lean Manufacturing and AHP for Efficiency in Mining Equipment Motor Repairs: A Case Study

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Abstract

Small and medium enterprises (SMEs) in the motor engine repair sector for mining equipment face significant challenges, including inefficient spare parts management and reliance on third-party repairs. These issues lead to delays and inconsistencies, affecting the overall efficiency and productivity of the mining operations they support. To address these challenges, this study proposed a production model based on Lean Manufacturing principles, including Poka Yoke, Standardized Work, and the Analytic Hierarchy Process (AHP). The model aimed to streamline workflows, improve quality control, and enhance operational efficiency through systematic error prevention and decision-making frameworks. The implementation of the proposed model resulted in a 25% reduction in time lost per component, decreasing from 3.16 hours to 2.39 hours. Additionally, repair capacity increased by 7.77 hours per component, and the use of Poka Yoke led to a 32.6% reduction in errors related to spare parts. The standardization of third-party jobs through Kaizen and AHP further reduced non-compliant work by 9%. The study's findings demonstrated significant improvements in the operational efficiency of SMEs in the motor engine repair sector, contributing to the overall productivity and profitability of the mining industry. This research provides a robust framework for addressing operational challenges and highlights the socio-economic benefits of adopting Lean Manufacturing principles. Future research should explore the further integration of advanced technologies and continuous improvement methodologies to sustain the gains achieved and to adapt to evolving industry needs.

Keywords
Lean Manufacturing, Analytic Hierarchy Process (AHP), Non-Destructive Testing (NDT), Mining Equipment, Operational Efficiency.

Introduction
The sector of small and medium enterprises (SMEs) providing motor engine repair services for mining equipment plays a crucial role in ensuring the operational efficiency of the mining industry. These SMEs are essential for maintaining and repairing the engines that power the mining equipment (Adam & Alarifi 2021). The reliability and effectiveness of these repair services directly impact the productivity and profitability of mining operations, highlighting the significance of SMEs in this niche sector. By ensuring that the engines powering mining equipment are in optimal condition, these SMEs contribute to the smooth functioning of the mining industry, which is vital for various sectors of the economy that rely on mined resources. However, despite their importance, SMEs in the motor engine repair sector face significant challenges that hinder their production processes. One of the primary problems plaguing these SMEs is the inefficiency in their repair services, often stemming from poor management of the spare

parts supply process (Khamis & Chen 2022). The lack of an effective system for sourcing and managing spare parts leads to delays in repairs, impacting the overall service quality and customer satisfaction. Moreover, reliance on third-party repair services for components further exacerbates the inefficiencies in the repair process, as delays and inconsistencies in these external repairs can disrupt the entire maintenance workflow (Dai et al. 2021). Additionally, deficiencies in Non-Destructive Testing (NDT) processes contribute to the subpar quality of repairs, posing risks to the reliability and safety of the repaired equipment.

Addressing the challenges faced by SMEs in the motor engine repair sector is crucial not only for the sustainability of individual businesses but also for the overall efficiency of the mining industry. Resolving these issues is paramount to enhancing the competitiveness and operational effectiveness of SMEs providing repair services for mining equipment (Sahoo & Ashwani 2020). By streamlining the spare parts procurement process, improving the reliability of third-party repair services, and enhancing NDT procedures, these SMEs can elevate their service quality and efficiency. This, in turn, will have a ripple effect on the mining sector, ensuring smoother operations, reduced downtime, and increased productivity. The existing literature underscores the importance of bridging the knowledge gap in addressing the operational challenges faced by SMEs in the motor engine repair sector serving the mining industry. Introducing a production model based on Lean Manufacturing principles, such as Poka Yoke, Standardized Work, and Analytic Hierarchy Process (AHP), holds promise in revolutionizing the repair processes of these SMEs (Raharjo 2019). Lean Manufacturing tools offer systematic approaches to optimize production processes, eliminate waste, and enhance overall efficiency. By integrating these methodologies into the operations of SMEs providing motor engine repair services for mining equipment, it is possible to streamline workflows, improve quality control, and boost productivity.

In conclusion, the sector of SMEs specializing in motor engine repair for mining equipment plays a vital role in supporting the operational integrity of the mining industry. However, challenges such as inefficient spare parts management, reliance on third-party repairs, and deficiencies in NDT processes hinder the optimal performance of these SMEs. Addressing these challenges through the implementation of Lean Manufacturing tools presents a promising opportunity to enhance the efficiency and competitiveness of SMEs in this sector, ultimately benefiting the mining industry as a whole. This research aims to contribute to filling the existing knowledge gap by proposing a production model grounded in Lean Manufacturing principles to empower SMEs in delivering high-quality repair services to the mining sector.

2. Literature Review

2.1 Application of Lean Manufacturing in Engine Repair in the Mining Sector

The Lean Manufacturing methodology has been extensively studied in various business contexts, including the mining sector. Iranmanesh et al.(2019) emphasize that Lean culture can moderate the relationship between Lean Manufacturing practices and the sustainable performance of companies. This research underscores the importance of organizational culture in the effective implementation of Lean practices. Additionally, Negrão et al. (2019) examine the relationship between Lean Manufacturing and business performance, demonstrating adherence to the S-curve theory, suggesting that Lean implementation can have a nonlinear impact on organizational performance. In a more specific context, Novirani (2024) explores the application of Lean Manufacturing to minimize waste in the production process of tin stabilizers. This study highlights how reducing lead time can lead to more efficient production processes and lower production costs. Furthermore, Qureshi et al.(2022) investigate Lean implementation in manufacturing systems for small and medium-sized enterprises (SMEs), indicating that this methodology can offer solutions to the sustainability challenges these organizations face.

2.2 Application of Standardized Work in Engine Repair in the Mining Sector

The Standardized Work methodology, within the context of engine repair in the mining sector, has garnered interest in academic literature. Manurung (2024) conducts a literature review on Lean Manufacturing implementation and emphasizes the importance of Standardized Work as an integral part of this methodology. This approach underscores the need to establish standardized processes to enhance efficiency and quality in engine repair. Additionally, Effendi (2023) analyzes Lean Manufacturing strategies in plastic packaging production, highlighting efficiency as a result of implementing standardized practices. This study emphasizes how process standardization can lead to significant improvements in operational efficiency. On the other hand, Olu-Lawal (2024) reviews Lean Manufacturing's application in industrial engineering, emphasizing the importance of work standardization to reduce waste and enhance efficiency in industrial processes.

2.3 Application of Poka Yoke in Engine Repair in the Mining Sector

The Poka-Yoke methodology, focusing on error prevention through fail-safe process design, has been researched in engine repair environments in the mining sector. Ganesan (2023) presents a case study on Lean Manufacturing implementation to enhance production efficiency in an electronics company in Malaysia. This study highlights how defect identification and elimination, fundamental in Poka Yoke, can lead to higher quality products and more efficient processes. Moreover, Saraswati (2024) develops a sustainable competitive strategy using tools such as process activity mapping and value stream mapping, which are essential in the Poka Yoke methodology. This approach underscores the importance of identifying and correcting errors in manufacturing processes to achieve a sustainable competitive advantage in the industry.

2.4 Application of AHP in Supplier Management in Engine Repair in the Mining Sector

The Analytic Hierarchy Process (AHP) methodology has been utilized in supplier management in various contexts, including the mining sector. Rahman (2023) investigates the impact of Lean Manufacturing on productivity and layout design in the sewing section of a textile industry. This study highlights how reducing non-value-added tasks, a fundamental principle of AHP, can enhance efficiency in production. Additionally, Alexander & Iskandar (2023) present a case study on Lean Manufacturing implementation in aluminum cable ladder manufacturing companies, emphasizing the use of value stream mapping, a technique compatible with AHP. This approach underscores the importance of hierarchically evaluating and selecting suppliers to improve efficiency and quality in engine repair processes in the mining sector.

3. Methods

3.1 Basis of the Proposed Model

Figure 1 illustrates a service model based on Lean Manufacturing philosophy and the Analytic Hierarchy Process (AHP) applied to engine overhaul services. This model focused on service efficiency through four key components: Poka Yoke, Standardized Work and AHP, Standardized Work, and Continuous Improvement. The implementation of Poka Yoke centered on workstation observation, idea selection through brainstorming, plan design, implementation, and subsequent monitoring and closure.

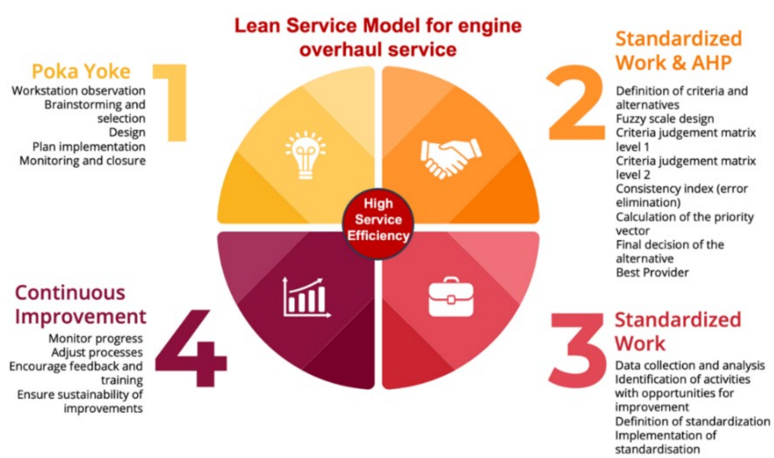

Figure 1. Proposed Model

The Standardized Work and AHP component involved defining criteria and alternatives, designing a fuzzy scale, developing criteria judgment matrices at two levels, eliminating errors through the consistency index, calculating the priority vector, and making final decisions to select the best provider. The Standardized Work included data collection and analysis, identifying activities with improvement opportunities, and defining and implementing standardization. Lastly, Continuous Improvement involved progress monitoring, process adjustments, promoting feedback and training, and ensuring the sustainability of the improvements implemented. This model aimed to optimize service efficiency through the integration of Lean and AHP tools, ensuring a high level of service efficiency.

3.2 Description of the model components

The proposed Lean Service Model for engine overhaul services offers a significant contribution to the existing literature by integrating Lean Manufacturing principles with the Analytic Hierarchy Process (AHP). This model aims to enhance service efficiency by systematically addressing common issues in engine overhaul processes through structured methodologies. The model incorporates key philosophies such as continuous improvement, error prevention, and standardization, which are fundamental to Lean Manufacturing. By embedding AHP, the model also introduces a robust decision-making framework to optimize service operations. The following sections provide a detailed explanation of each component of the model.

3.2.1 Poka Yoke Implementation

The first component of the model, Poka Yoke, focused on preventing errors in the service process through a systematic approach. This stage began with the observation of workstations to identify potential error sources. Observational techniques were employed to gather comprehensive data on the existing processes, identifying areas where mistakes were most likely to occur. This initial step was crucial for understanding the current state and pinpointing the root causes of inefficiencies. Following the observations, brainstorming sessions were conducted to generate ideas for error-proofing. This collaborative approach ensured that various perspectives were considered, leading to innovative solutions. The selected ideas were then translated into detailed designs, which included specific error-prevention mechanisms tailored to the identified issues. The next step involved the implementation of these designs. Detailed plans were formulated, specifying the resources, timelines, and responsibilities required for execution. Once implemented, continuous monitoring was conducted to assess the effectiveness of the error-proofing measures. Feedback was collected and analyzed, leading to further refinement and the eventual closure of the implementation phase. This iterative process ensured that the error-prevention mechanisms were robust and sustainable.

3.2.2 Standardized Work and AHP Integration

The second component, Standardized Work and AHP, integrated structured work practices with a multi-criteria decision-making framework. The first step in this stage was the definition of criteria and alternatives relevant to the service process. Criteria were developed based on factors such as cost, quality, and efficiency, which are critical for evaluating different service strategies. A fuzzy scale was designed to handle the inherent uncertainties in the decision-making process. This scale allowed for more flexible evaluations by accommodating the ambiguity and imprecision associated with human judgments. The criteria judgment matrix was then constructed in two levels. The first level involved pairwise comparisons of the criteria, while the second level focused on comparing the alternatives against each criterion. The consistency index was calculated to ensure the reliability of the judgments. Any inconsistencies were addressed through error elimination techniques, enhancing the accuracy of the decision-making process. The priority vector was then computed, providing a clear indication of the relative importance of each criterion. Finally, the alternatives were evaluated, and the best provider was selected based on the computed priority vectors. This systematic approach ensured that the decision-making process was transparent, objective, and aligned with the strategic goals of the service operation.

Standardized Work

The third component, Standardized Work, emphasized the importance of establishing uniform procedures to enhance service consistency and efficiency. This stage began with comprehensive data collection and analysis. Data from various service activities were gathered and scrutinized to identify areas with improvement opportunities. This analytical approach provided a clear understanding of the current performance levels and highlighted specific processes that required standardization. Based on the analysis, standard procedures were defined for critical activities. These procedures were documented in detail, specifying the best practices to be followed by the service personnel. The implementation of these standardized procedures was then carried out, ensuring that all staff members adhered to the established guidelines. Training sessions were conducted to familiarize the staff with the new procedures. Continuous monitoring was also instituted to ensure compliance and identify any deviations. This proactive approach ensured that the standardized work practices were effectively integrated into the daily operations, leading to improved service quality and efficiency.

Continuous Improvement

The final component, Continuous Improvement, focuses on sustaining the gains achieved through the previous stages and fostering a culture of ongoing enhancement. Progress was monitored regularly to assess the effectiveness of the implemented changes. Key performance indicators were tracked, and any deviations from the desired performance levels were addressed promptly. Processes were adjusted based on the feedback received from the monitoring activities. This adaptive approach ensured that the service operations remained responsive to changing conditions and evolving customer needs. Additionally, feedback from the service personnel was encouraged and utilized to identify further improvement opportunities. Training programs were also an integral part of this stage, aimed at equipping the staff with the necessary skills and knowledge to contribute to the continuous improvement efforts. The sustainability of the improvements was ensured by embedding the continuous improvement mindset into the organizational culture. This commitment to perpetual enhancement ensured that the service operations remained competitive and capable of meeting high service efficiency standards.

3.3 Model Indicators

To evaluate the effectiveness of the proposed service model, specific metrics were developed to monitor and manage its performance within the case study. These metrics provided a systematic approach to performance evaluation, ensuring that all essential aspects of the production process were thoroughly measured and analyzed. This facilitated a detailed assessment of the impact of the model on the level of engine overhaul service.

Service Efficiency Rate: The percentage measure of the efficiency of the service process, calculated by comparing the total time spent on productive activities to the total available time.

$$\text{Service Efficiency Rate} = \frac{Total\ Productive\ Time}{Total\ Available\ Time} \tag{1}$$

Time Lost Due to Problems with New Spare Parts: The average time lost per component due to issues arising from new spare parts, which affects the overall service process efficiency.

$$\text{Time Lost Due to Problems with New Spare Parts} = \frac{Total\ Hours\ lost\ due\ to\ new\ spare\ parts}{Total\ Number\ of\ Components} \times 100 \tag{2}$$

Time Lost Due to Problems with Third Party Work: The average time lost per component due to delays or issues caused by third-party service providers during the service process.

$$\text{Time Lost Due to Problems with Third Party Work} = \frac{Total\ Hours\ lost\ due\ to\ third\ party\ work}{Total\ Number\ of\ Components} \times 100 \tag{3}$$

Time Lost Due to Waiting Time for NDT: he averages time lost per component while waiting for Non-Destructive Testing (NDT) to be performed, affecting service timelines.

$$\text{Time Lost Due to Waiting Time for NDT} = \frac{Total\ Hours\ lost\ for\ waiting\ NDT}{Total\ Number\ of\ Components} \times 100 \tag{4}$$

4. Validation

4.1 Initial Diagnosis

In Figure 2, the problem tree illustrates the summary of the diagnostic conducted in the case study to identify the reasons and root causes generating the research problem of low efficiency in the engine overhaul service. The figure highlights a significant technical gap, where the case study efficiency rate was 86.25%, lower than the industry standard of 96.28%. This discrepancy resulted in an annual economic impact of 47,380 USD, equivalent to 4.73% of annual revenue. The primary causes identified were delays in the assembly process, accounting for 74% of the problem, followed by delays in the dismantling process at 20%, and other factors at 6%. At the level of root causes, delays in the assembly process were broken down into delays due to incorrect or damaged parts arriving for assembly (27.8%), late delivery of parts for assembly (4.8%), shutdowns due to non-compliant third-party service (22.3%), delays due to unnecessary overhead crane runs (5.6%), and other minor factors (12.4%). Delays in the dismantling process included downtime due to incomplete Non-Destructive Test (NDT) work (18.0%) and other factors (1.3%). This diagnostic aimed to break down and quantify the specific causes contributing to overall inefficiency, providing a clear basis for developing focused improvement strategies.

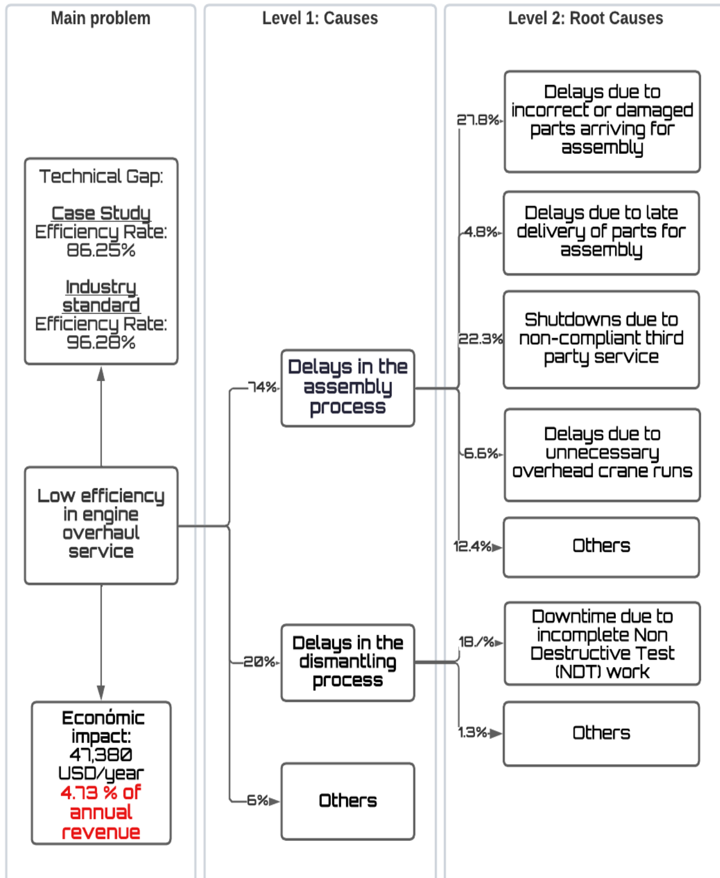

Figure 2. Problem Tree

4.2 Implementation of the model in the case study

Implementation of the Poka Yoke Tool - Reduction of shutdowns due to missing parts

The Poka Yoke tool was implemented in the workshop with the aim of reducing downtime in the traction motor repair process due to missing parts. The detailed design included several stages, starting with the observation of the workstation. In this phase, parts handling problems were identified, specifically in the logistics activity of transporting and checking spare parts. Solutions were proposed through brainstorming, selecting the implementation of a mobile multilevel tray that allows the organization and verification of parts in an efficient way.

The design of the tray was based on the repair history, ensuring that each part had its specific and marked location, thus facilitating quick and accurate review by logistics staff. The trays cost USD 1465.71 per unit to manufacture, and their implementation required staff training in their correct use, conducted in one initial and three feedback sessions. The monitoring and closure phase was carried out for an additional month to ensure the effectiveness of the system. As a result, during the first year, a 74% reduction in spare parts related incidents was observed, reducing lost time from 5.51 hours per component to 1.39 hours. In the second year, the indicator improved further, reaching 0.7 hours per component.

Figure 3 shows the design of a multi-level segregation tray used for the implementation of the Poka Yoke tool in the workshop. This tray is intended to organize and verify the parts needed for the repair of traction motors in an efficient manner.The design of the tray includes multiple levels where each part has its specific and marked location, which facilitates a quick and accurate review by the logistics staff. The tray is mobile, allowing it to be easily moved within the workshop, thus improving the efficiency of the logistics process by reducing human errors related to the quantity and quality of parts.The model depicted in the figure shows a robust structure with clear compartments and divisions, ensuring that each part is in its correct place and protected from damage. The tray has wheels that facilitate its movement and allow it to be positioned in different areas of the workshop as required.

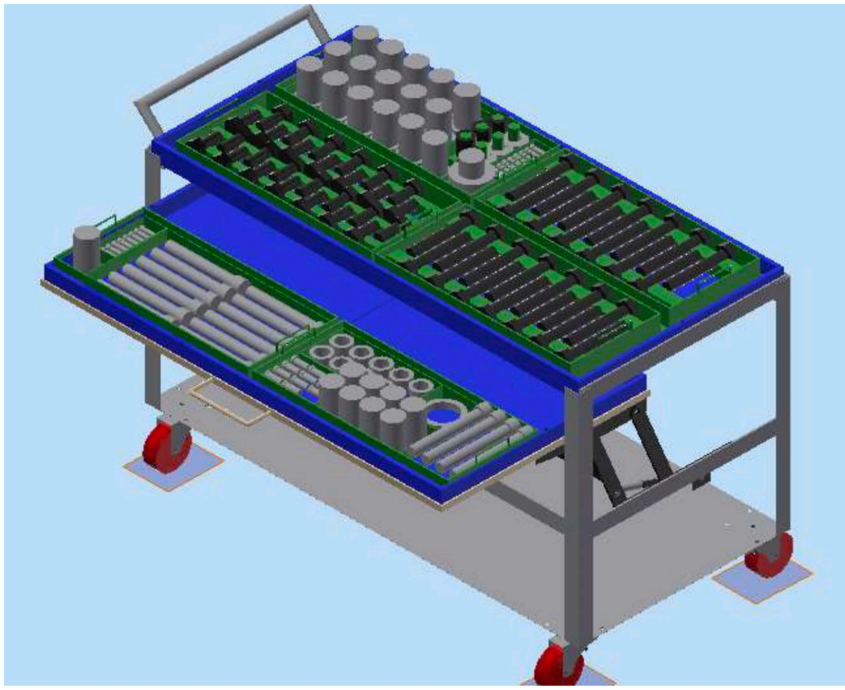

Figure 3. Design of the segregation trolley

4.3 Implementation of STANDARDISATION OF WORK - Supplier selection for engine parts repair Traction
The process of work standardization for the selection of suppliers of repair parts in traction motors was initiated with the aim of unifying and homologating the procedure of selection, using the Diffuse Hierarchical Analytical Method (AHP). Criteria and alternatives were defined for the evaluation, where the most representative suppliers were selected: Komatsu Rebuild Center Peru (KRCP), ABB, KMC, and KRCC. The relevant criteria, agreed upon by the responsible team, included price, delivery time, transport cost and average annual failure probability. A diffuse rating scale based on the Saaty scale was used, where each criterion and supplier were evaluated through linguistic analysis.

The hierarchical analysis allowed to calculate the priority vector for each criterion and supplier, determining that ABB was the best option to perform repair services. This result was obtained after a detailed quantitative analysis, where ABB showed a final weighting of 0.54, outperforming the other suppliers in most of the evaluated criteria.
Once the supplier was selected, modifications were implemented in the SAP system to automate service registration and ensure compliance with established standards. The Service Entry Sheet (SES) was configured to record and validate the services provided, ensuring quality and facilitating the payment process. In addition, the personnel involved were trained and constant monitoring was carried out to ensure the effectiveness of the new procedure.
In conclusion, the standardization of work through AHP not only facilitated the selection of the best supplier, but also strengthened the lean culture within the company, efficiently targeting the reactors identified in the KAIZEN process. The quantitative results included reduced delivery time and increased reliability in outsourced services, which contributed significantly to the efficiency of the traction motor repair process.

The figure 4 shows the proposed flowchart for selecting suppliers for the repair of traction motor components. The process starts with determining whether third-party service is required. If it is not required, the flow ends. If it is required, a service request is made to ABB by the technical planning area. Subsequently, a quotation is requested from ABB, which includes certifications of the technical personnel and testing equipment. If the quotation meets the requirements, a service order is generated in the SAP system. Then, the components are sent to ABB's third-party workshop for repair. Once the repair is completed, the components return to the main workshop. Next, technicians schedule functionality tests for the components. The service entry sheet (SES) is generated in SAP, which is a requirement for payment to the supplier.

Finally, the supervisor approves the service, and the supplier is paid, thus concluding the process.

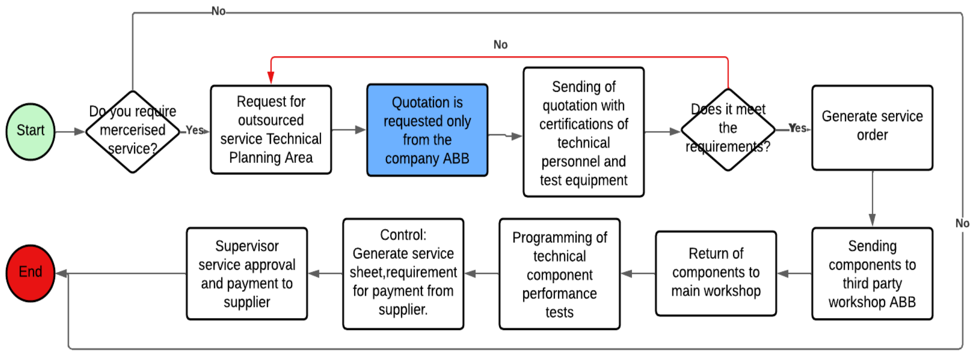

Figure 4. Proposed supplier selection for the repair of traction motor repair components

4.4 Implementation of STANDARDISATION OF WORK - Reduction of unproductive time for incomplete NDT work

Standardization of work to reduce unproductive times for incomplete NDT jobs focused on identifying and mitigating causes that generated delays in the process of repair of traction motors. During the analysis, variability in NDT process activities was found to be significant, with a total percentage level of 34%, The European Commission has recently published a report on the European Union's research and development program. These delays were mainly attributed to the time saturation of NDT specialists. The analysis identified activities that did not require specialists and could be delegated to mechanical technicians, This eliminated the need for additional transfers and manipulations. Specific activities to be carried out by mechanical technicians were defined and standardized procedures were developed in collaboration with NDT specialists. In addition, three magnetization equipment were purchased for use by the technicians, allowing NDT activities to be carried out in the evaluation bay.

The implementation of standardization was carried out in four stages: acquisition of equipment, training of the personnel involved, monitoring of activities and observation. The results of the initial assessment showed a 25% reduction in time lost per component, decreasing the indicator from 3.16 hours to 2.39 hours per component. During 2021, a reduction to 0 lost hours per component was achieved, exceeding the initial expectations of the project. The functional validation of the project demonstrated a significant improvement in the efficiency of the traction motor repair process, Increasing repair capacity by 7.77 hours per repaired component. The reduction of unproductive times due to incorrect and damaged spare parts was achieved by implementing the Poka Yoke tool, achieving a 32.6% reduction in causes. In addition, the standardization of non-compliant third-party jobs through the Kaizen process and AHP hierarchical analysis allowed a reduction of 9%. The standardization of work in NDT activities and the delegation of techniques and knowledge resulted in a 25% decrease in unproductive time.

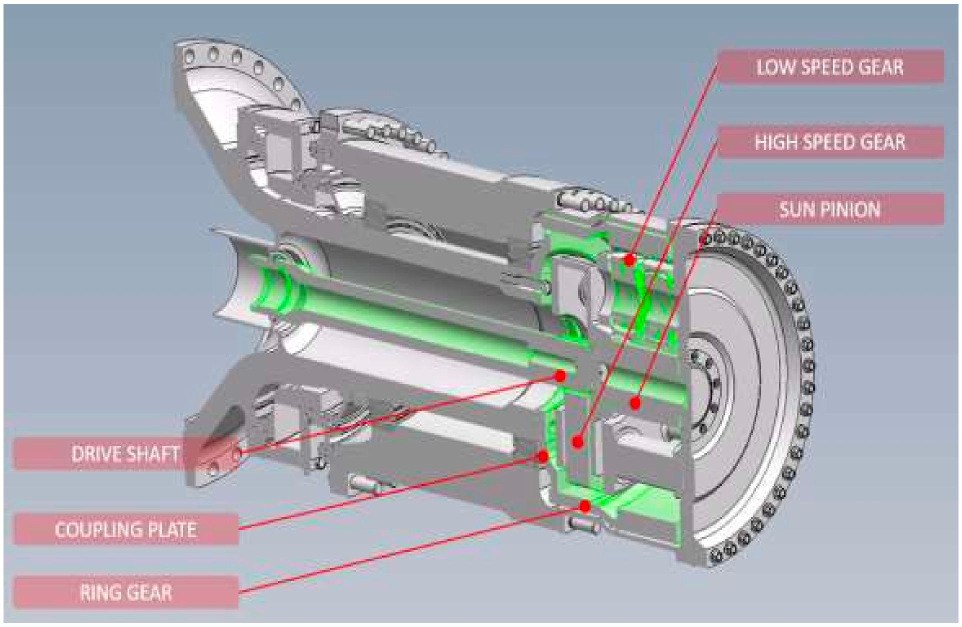

Figure 5. Procedure developed for the implementation of NDT activities. The location of each part is detailed according to the following scheme

Figure 5 illustrates a procedure developed for the implementation of Non-Destructive Testing (NDT) activities on traction motor components. The image provides a detailed schematic of various parts of a component, specifically a gearbox. The labeled parts include the Drive Shaft, Coupling Plate, Ring Gear, Low-Speed Gear, High-Speed Gear, and Sun Pinion. Each part is indicated with lines that precisely locate it within the component schematic. The purpose of this figure is to offer a clear visual guide for the accurate location and handling of each part during NDT activities, following the standardized work procedure implemented. One advantage of this visual guide is that it significantly reduces the potential for errors by providing precise locations and names for each part, thereby improving the efficiency and accuracy of NDT processes. However, a potential drawback is that relying solely on visual aids might not be sufficient for all technicians, particularly those who might need more comprehensive training or detailed procedural instructions to fully understand and execute the NDT tasks effectively.

5. Results

Table 1. presents the key results of validating the proposed Lean and AHP service model aimed at addressing the research problem.

Table 1. Results of the validation of the proposed model

Indicator	Unit	As-Is	To-Be	Results	Variation (%)
Service efficiency rate	%	86.25%	96.28%	89.22%	3.44%
Time lost due to problems with new spare parts	hours/component	5.51	0.79	1.39	-74.77%
Time lost due to problems with third party work	hours/component	3.78	2.11	0.9	-76.19%
Time lost due to waiting time for NDT	hours/component	3.16	1.49	2.39	-24.37%

The service efficiency rate increased from 86.25% to 89.22%, demonstrating a significant improvement. Additionally, the time lost due to problems with new spare parts was reduced by 74.77%, dropping from 5.51 hours per component to 1.39 hours per component. The time lost due to problems with third-party work decreased by 76.19%, from 3.78 hours per component to 0.9 hours per component. Furthermore, the time lost due to waiting for NDT (Non-Destructive Testing) was reduced by 24.37%, from 3.16 hours per component to 1.49 hours per component. These results highlight the effectiveness of the model in enhancing service efficiency and reducing operational delays.

6. Conclusions

The main findings of this study indicate that the implementation of Lean Manufacturing tools, such as Poka Yoke, Standardized Work, and the Analytic Hierarchy Process (AHP), resulted in a significant improvement in the operational efficiency of small and medium-sized enterprises (SMEs) engaged in traction motor repair for mining equipment. A 25% reduction in time lost per component was achieved, decreasing the indicator from 3.16 hours to 2.39 hours per component. Additionally, repair capacity increased by 7.77 hours per repaired component. The Poka Yoke tool led to a 32.6% reduction in causes of unproductive time due to incorrect and damaged spare parts, and the standardization of non-compliant third-party jobs through Kaizen and AHP allowed for a 9% reduction.

The importance of this research lies in its contribution to enhancing the competitiveness and efficiency of SMEs in the motor repair sector, a critical area for the continuous operation of the mining industry. By addressing key operational issues such as inefficient spare parts management and reliance on third-party services, this study provides a roadmap for optimizing repair and maintenance processes, thereby ensuring the sustainability and growth of these companies.Contributions to the field include the effective integration of Lean Manufacturing principles with AHP, offering a systematic approach to decision-making and continuous improvement in the motor repair environment. This combination not only optimizes internal processes but also establishes a framework for more efficient supplier evaluation and selection. The results demonstrate the feasibility of applying Lean methodologies in SMEs within the mining sector, providing a replicable model for other industries facing similar challenges.

Final observations suggest that, while the results are promising, further studies are needed to assess the long-term impact of these improvements and explore the integration of advanced technologies, such as automation and data analytics, to continue enhancing service efficiency and quality. Additionally, fostering a culture of continuous improvement among staff is recommended to ensure that the implemented practices are sustained and evolve over time. Lastly, researchers are encouraged to explore new research directions that expand the scope and application of these methodologies in various industrial contexts.

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Biographies

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This is his first conference where he will seek professional and personal recognition.