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Original Article

Enhancing Service Efficiency in Peruvian Automotive Workshops through the Integration of SMED, KANBAN, and TPM: A Lean-Based Empirical Study

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Abstract - *The automotive industry in Peru is a key sector of the economy, with steady growth in vehicle sales, leading to increased demand for maintenance services. However, auto repair shops face critical challenges such as delivery delays, post-service complaints, and inefficient resource management due to unplanned mechanical failures, prolonged setup times, and stockout issues. This study proposes a model based on TPM, SMED, and Kanban. TPM, through preventive and autonomous maintenance, aims to reduce unplanned failures and increase equipment availability. SMED addresses the reduction of setup times by standardizing processes. Kanban improves inventory management using boards and cards that optimize turnover and reduce stockouts. Simulations were conducted using Arena software, and statistical validations, including Kolmogorov-Smirnov and Chi-square tests, were applied to analyze time distributions with Input Analyzer. Kanban was validated through a baseline and improved model using a pilot test with Kanban boards and cards, along with Arena software simulation, while TPM and SMED were evaluated with joint simulations using Input Analyzer, ensuring 95% confidence intervals. The results show an increase in service level from 82.67% to 92.72%, surpassing industry standards and confirming the model's effectiveness in improving operational efficiency. This approach is replicable and contributes to the competitive development of the automotive sector, enhancing customer satisfaction in repair shops in emerging markets.*

Keywords - *Service Level, TPM, KANBAN, SMED, Mechanical workshop.*

1. Introduction

The automotive sector in Peru has a significant impact on the national economy. According to the Automotive Association of Peru (AAP), the industry has maintained continuous growth of 1.74% since the first half of 2023. Tuesta, V. et al [1] report an increase of over 6% in vehicle sales, which leads to the sale of more mechanical spare parts. Likewise, this sector contributes positively to the state in terms of new job creation, and despite experiencing a contraction of -0.4% in 2023, the sector has a contribution to GDP of 10.50%. In addition, the study by Briceño-Guzman, S et al [2], indicates that the sector has been a pillar of support for the economy during the first months of 2021; however, delays in repairs have caused a loss of potential customers. This is supported by Tuesta, V. et al [1], where they highlight in their study the importance of market share, where the main competitors of mechanical workshops are agencies and dealerships, which have differentiated protocols and have highly competitive advantages. For this reason, the level of service is one of the main points to improve in a mechanical workshop. This need for improvement becomes more evident when analyzing real data from the workshops under study, which currently reports a service level of 82.6%, while the automotive industry standard stands at 92.72% [2]. This technical gap of 10.12% has a direct impact on customer satisfaction and limits compared to dealerships and authorized service centers. Furthermore, this low service level results in an estimated annual economic loss of PEN 219,586, representing 35.35% of the workshop´s total annual revenue.

Repair shops face constant challenges in terms of service quality, customer satisfaction and operational efficiency. For this reason, ensuring a first-class level of service is a priority. In this article we will seek to increase the level of service of the mechanical workshop which has two main reasons, firstly, according to the study by Tuesta, V. et al [1] the level of service was affected by the lack of planning and coordination of tasks, this leads to long waits or queues in the processes, which in turn causes delays in service at the service station from deliveries outside the established time, this due to excessive time between setups, [2][3][4] errors that are attributed to the repair which create reprocesses [2][5], overload and improper use of equipment and lack of maintenance of the same [6][7][8];

In this study, delays account for 70.83% of the factors contributing to the low service level. The most significant causes are concentrated in three main aspects: excessive setups, representing 46.61%; lack of equipment maintenance, accounting for 23.98%; and improper use of equipment, which represents 19.46%.

On the other hand, the second reason that affects the level of service in the workshop is after-sales complaints which can be generated by poorly prepared diagnoses prior to maintenance, low-quality spare parts that are acquired due to inefficient management of spare parts [9] and finally the registration of the order before delivery to ensure that the delivery is complete with everything agreed with the customer. Post-service complaints represent 29.17% of the total effects resulting from the low service level. Within this category, 68.13% are attributed to the use of low-quality spare parts, while the remaining 31.87% are due to other causes.

To increase the service level, the implementation of TPM, SMED and KANBAN tools is proposed. The SMED tool is applied to reduce excessive setup times, as the lack of standardization during changeovers has been shown to be a significant area for improvement [2] [4][10]. In parallel, two key pillars of TPM- preventive and autonomous maintenance are applied. According to the study by M.D.O., dos Reis et al. [7], equipment downtime and insufficient maintenance can be effectively addressed through these practices.

Finally, Briceño-Guzmán, S., Flores-Pérez, A. [2] indicate in their research that the KANBAN method is applied to ensure proper inventory management of spare parts [9]. The issue of purchasing low-quality spare parts due to stock shortages is addressed by anticipating procurement needs. Evidence suggests that stock shortages can be mitigated through timely ordering, thereby avoiding inventory disruptions.

Unlike previous studies that focus on isolated tools or general operational problems [1], this research proposed a combined approach based on the integrated application of TPM, SMED, and KANBAN within a Peruvian automotive workshop. This represents a novel contribution to the literature, particularly in the local context, where Lean methodologies have not yet been applied in a combined manner.

This research contributes to the academic debate on reducing untimely order deliveries, inventory management, and proper equipment maintenance, while also analyzing the interrelationship between mechanical workshops, economic performance, and social development. The article is structured as follows: a complete review of the state of the art of the literature, a detailed description of the methodology employed, a thorough analysis of the case studies, the presentation and discussion of the results, and a concluding summary.

2. Literature Review

From the literature review, two studies focused on improving delivery times through the use of SMED and 5S as main tools. These works provide a variety of approaches to the subject, providing detailed knowledge in areas such as automotive, process management and the reduction of changeover times. On the other hand, there are two investigations focused on equipment maintenance and availability, where the application of Total Productive Maintenance (TPM) is proposed for machine supervision and upkeep.

The availability of equipment as well as the maintenance of these is essential for mechanical workshops. A key study focuses on improving inventory management with a significant impact on the decisions of the participants regarding imports, purchases and inventory rotation. The results of all studies offer valuable insights for the development of strategies to improve efficiency and service levels in the automotive, manufacturing and machine shop sectors. Increasing the level of service in a company has a significant impact, as it creates a bond with the customer, which means that when high-quality service is delivered, service quality can be measured by the management of long waiting times or unnecessary queues [2] as well as post-service complaints [5][11]. The solutions proposed by different researchers, such as the use of Lean Manufacturing tools (VSM, SMED, 5S), KANBAN and TPM, have proven to be effective in improving the level of service [7][12][13] and operational efficiency in various contexts within the automotive industry [13-15].

2.1. SMED Tool Application

The implementation of the SMED tool minimizes tool set-up and changeover times, converting internal to external activities whenever possible [2-4][16]. This approach makes it possible to significantly reduce vehicle repair [15] and delivery times, resulting in improved workshop operational efficiency. Tuesta, V., Viacava, G., Raymundo, C. [1] indicates in his study the critical analysis of current knowledge on the problem of low level of service and after-sales service in the industry, as well as the suggested solutions, show a coincidence in identifying the lack of planning and coordination of tasks as one of the main causes of the problem.

In addition, the study highlights inadequate time management in mechanical workshops, a key factor that contributes to the generation of long waits and inefficiency in vehicle repair. The pilot proposal validated at one of the largest maintenance service dealerships was able to reduce the two-hour delivery time, a decreased in the queue before each process, and a decline in the percentage of vehicles delivered after the deadline from 28% to 8%. López, Y.M et al [17] present an optimization model to improve efficiency in the production of flexible packaging in a small company in the plastics sector in Peru, addressing problems such as long setup times, unplanned failures, and ineffective work order scheduling. Tools such as Johnson's Method were applied, which reduced total processing time by 23.13% SMED, which decreased setup times by 36.27% to 51.10% and Total ™ Productive Maintenance which increased the average time between failures by 20.63% to 79.30%, a 36.03% reduction in non-conforming products and the elimination of additional penalty costs.

2.2. TPM Tool Application

With the TPM tool, specific preventive maintenance plans are implemented for key workshop equipment. Daily, monthly, and annual inspections are carried out to ensure the correct operation of the machines and prevent unforeseen failures [1][6][7][14]. Standard Operating Procedures (SOPs) are also developed to ensure that operators use the machines properly and safely. M.D.O dos Reis et al [7] analyze the implementation of a Total Productive Maintenance (TPM) system in a metallurgical company dedicated to the manufacture of clutches and hydraulic controls, with the aim of reducing downtime and improving the overall efficiency of equipment in CNC lathes and machining centers. Key pillars were implemented, such as problem elimination, autonomous maintenance with daily inspections and cleaning tasks by operators, planned maintenance with plans tailored to the specific needs of the machines, and continuous training of workers in maintenance tasks.

The results obtained included a reduction in downtime, a 5% increase in operational efficiency, and an improvement in reliability indicators. However, limitations were identified, such as the resistance of workers to adapt to new routines and the need to integrate a computer system for maintenance management. The study demonstrates how the application of TPM can significantly improve operational efficiency and reduce costs through a comprehensive and participatory approach to industrial maintenance. G. Pinto et al [15] describe in their study the implementation of a Total Productive Maintenance (TPM) plan in a production line in the automotive sector, with the aim of improving the reliability of the line and reducing losses caused by failures in critical machines. Autonomous maintenance plans, carried out by the operators, and planned preventive maintenance were applied, with specific interventions on five key machines. The results showed a 3.5% reduction in the loss due to failure (NOI) ratio and a decrease in downtime on the intervened machines. The implementation of the TPM had a positive impact on the reliability and efficiency of the line, demonstrating the effectiveness of the strategies proposed in the automotive industry.

2.3. Kanban Tool Application

S. Briceño-Guzman et al [2] presents in their study the implementation of Lean Service tools- The results obtained were an improvement in on-time deliveries, which increased from 84% to 91.5%, a reduction in days with a backlog of work from 10 to 2, and a decrease in filling incidents from 16% to 8%. The implementation of the KANBAN is aimed at improving spare parts inventory management. KANBAN cards are established for common and special spare parts, allowing the differentiation of the available stock. The cards are placed on the KANBAN board, located in a strategic place in the workshop, facilitating access and visualization [2][9][18]. The pilot plan allows the collection of information to develop an advance order so as not to incur stock shortages [5][6] that occur in the purchase of generic spare parts that are not suitable for the repair of the vehicle.

3. Methodology

In the previous chapter, the literature review was presented, where it was noted that in the literature there are some thematic gaps in the existing models, which is why it has been listed for each component in Table 1 (Appendix), where the following criteria were established: literature review, engineering tool, case study and metrics. The purpose of this is to look for models in literature that have implemented techniques or tools in a mechanical workshop and present the tools and key indicators, such as MTTR, MTBF, service level, availability and inventory turnover metrics, that are also proposed in the present study. By reviewing these models, it is possible to validate the applicability of the tools discussed in the selected literature.

The analysis revealed that in most models, only between 5 and 7 of the evaluated criteria were met. The model presented in this study is based on the implementation of the SMED tool, which focuses on the significant reduction of excessive times between setups in the mechanical workshop activities [2-4][16]. This approach enabled to streamline of operations and reducing the time spent by vehicles, optimizing the capacity of attention [5]. In addition, the second and fifth pillars of the TPM [7] were applied to increase machine availability, reducing the number of critical failures through an integrated approach to preventive and autonomous maintenance.

The application of the KANBAN method, through boards and tokens, improved inventory turnover and eliminated stockouts, ensuring the continuous availability of necessary spare parts [2][9]. In addition, the standard time indicator has been a crucial indicator in order to evaluate the improvement in the reduction of total repair time per vehicle. In combination with other performance metrics, this indicator supports the assessment of operational efficiency improvements achieved through the proposed model.

3.1. Proposed Method

There is a noticeable gap in the combined implementation of tools such as SMED, TPM and Kanban in the context of machine shops, especially in improving the service level. Although these tools have been widely used in the manufacturing industry to optimize time, availability, and inventory management, their integrated application in specific case studies, such as machine shops, has not been sufficiently explored. This highlights the need for a practical model to reduce vehicle dwell times, improve machine availability and ensure efficient inventory management. The proposed model seeks to address this gap and provide a framework to increase the competitiveness of machine shops in emerging markets. The proposed model is shown (Figure 1), which shows the objective, which is to reduce waiting times and optimize activities through the integration of SMED, TPM and Kanban.

In the case of the SMED, non-optimized internal activities and long equipment preparation time were identified as the main causes of delay. To solve this, certain internal activities were transformed into external ones through staff training and standardization of procedures, achieving a significant reduction in changeover times. TPM focused on addressing unplanned mechanical failures. Through the implementation of preventive maintenance, a schedule was established with rigorous planning for the prevention of this, while autonomous maintenance operators were trained in basic maintenance, inspection and cleaning tasks. This allowed for increased machine availability and reduced downtime. As for Kanban, its implementation focused on efficient inventory management through the use of visual boards and tabs. This facilitated the timely identification of replenishment needs and prevented stockouts, especially in fast-moving spare parts. In addition, minimum and maximum levels were established for inventories, optimizing turnover and ensuring the continuous availability of critical materials. Subsequently, a simulation of all the tools will be carried out for validation.

3.2. Model Components

3.2.1. Diagnosing the Problem

In this diagnosis, the low level of service in the mechanical workshop was identified as the main problem. The analysis began with the Ishikawa diagram, which allowed possible causes to be classified into key categories, followed by the Pareto diagram [14], which helped to prioritize the causes with the greatest impact. Subsequently, the problem tree was instrumental in understanding cause-and-effect relationships, highlighting how late deliveries and after-sales claims directly affected the service level. The VSM was then used to map the entire maintenance process [2], identifying bottlenecks and non-value-added activities. Finally, with the support of the Five Whys, the root causes were delved into to understand the underlying factors. This sequential approach allowed for a comprehensive analysis, identifying critical areas and establishing a solid foundation for improvement solutions.

3.2.2. Identification and Implementation of Tools

The second stage is the identification of tools, where a state-of-the-art search was carried out to collect information on cases and investigations carried out with respect to service level, time reduction, proper use of equipment and improvement of customer satisfaction where TPM, SMED and Kanban tools were identified in different articles, In the present research, the aim was to use the three tools in order to use them in parallel, covering most of the causes with a greater impact on the main problem.

The first tool was the SMED, where internal and external activities were identified at the configuration time. Based on the analysis, internal activities were redefined, outsourcing those that could be carried out in advance. In addition, standardized checklists and protocols were designed for each type of exchange. The execution of SMED made it possible to significantly reduce changeover times, increasing equipment availability and reducing standard time.

The second tool to be implemented was TPM, which focused on the pillars of preventive and autonomous maintenance with the aim of minimizing unplanned failures. This included training staff to perform regular inspections, establishing a preventative maintenance schedule for key equipment, and using logs to monitor machine performance. These actions made it possible to detect and correct potential failures before they became major problems, reducing downtime and improving equipment reliability.

The third tool to be implemented was KANBAN, to optimize inventory management. A Kanban system was designed that uses boards and cards to control the replacement of critical spare parts. Minimum and maximum stock levels were defined for each spare part, and the cards were coloured to indicate priorities. In parallel, a continuous flow was implemented in the supply process, ensuring the availability of materials at all times and avoiding stock shortages. This system was tested both in simulations and in a real environment, validating its effectiveness in maintaining the optimal level of inventories.

3.2.3. Validation

Once the improvement solutions were implemented, it was validated using Arena Simulator to model the process and evaluate changeover times with SMED, mechanical failures using TPM, and inventory management with Kanban. In addition, a pilot test was implemented with a board and Kanban cards (Figure 2), thus evaluating the replacement of spare parts in a real environment and complementing the results obtained in the simulation. The effectiveness of SMED was validated by significantly reducing changeover times, measured before and after implementation, while TPM was evaluated by decreasing the number of failures. For its part, Kanban demonstrated its impact in both the simulation and the pilot test, which improved the availability of spare parts and avoided stockouts. The re-evaluation reflected significant improvements, reduced times, greater availability of equipment and more efficient inventory management, confirming the effectiveness of the proposed model and its contribution by increasing the level of service of the workshop, exceeding the standard of 92.2% [2]. The process with the implementation of the proposed model is shown (Figure 3).

3.3. Indicators

The measurement of the results of the model will be obtained through the following indicators.

3.3.1. MTTR (Mean Time To Repair)

This is the average time it takes to repair a system or equipment after a breakdown, which is calculated with the total repair time and number of repairs [4][15][17].

$$MTTR = \frac{Total\ Time\ to\ Repairs}{Number\ of\ repairs} \quad (1)$$

The aim is to reduce the MTTR indicator for hydraulic lift to 4 hours and 30 minutes, for steering aligner to 4 hours and for air compressor to 3 hours.

3.3.2. MTBF (Mean Time Between Failures)

It indicates the average time during which the machine works correctly before a failure occurs, which is calculated with the total operating time and number of failures [4][15][17].

$$MTBF = \frac{\text{Total operating time}}{Number\ of\ failures} \quad (2)$$

This indicator seeks to demonstrate the proper operation of the machines, giving in the hydraulic lift 685.4 hours between failures, 607.75 hours of average operation between failures in an air compressor, and 1187.75 average hours between failures in the steering aligner.

3.3.3. Machinery Availability

Machinery availability measures the percentage of time a machine is operational and running compared to the total time it should be available on schedule. Hydraulic lifts are expected to have a minimum availability of 74.98%.

According to the steering aligners, 76.99% availability is expected. On the other hand, air compressors are expected to have a minimum of 64.98% availability.

3.3.4. Service Level

The level of service is a crucial KPI for research and for a machine shop, as it is closely linked to quality and customer satisfaction [15].

$$Service\ level = \frac{Orders\ Successfully\ Delivered}{Total\ orders}\ x\ 100 \quad (3)$$

An increase in the following indicator is sought to 93.43%, exceeding the stipulated standard, which is 92.2% [2]

3.3.5. Inventory Turnover

Inventory turnover is an indicator that measures the frequency with which movements of warehouses and inventories are made. In the case of the workshop, a focus was made on the inventory management of spare parts.

$$Inventory\ Rotation = \frac{Total\ Parts\ Used}{Average\ Spare\ Parts\ Inventory}\ x\ 100 \quad (4)$$

The aim is to increase turnover by 50% of inventory for better management of spare parts and not to overstock or fall into stock shortages.

4. Results

4.1. Description

The study scenario belongs to the mechanical workshop industry located in Lima, Peru, where they mainly serve light vehicles. The workshop presents common challenges in the sector, where a gap in the level of service has been identified, reporting by the company a value of 82.67%; however, the sector reflects that the acceptable value is 92.2%. This generated an economic impact of 35.5% of the annual turnover (Figure 7).

The workshop team consists of 10 operators, 2 administrative staff members and the workshop owner. Daily activities include preventative vehicle maintenance, corrective and diagnostics, as well as minor or major repairs. During the time of information gathering, the team was trained in the new tools, so that they are involved in the process, having the tools to perform the proper inspections and having the knowledge of how each of the tools works. Taking into account validation, the level of service will be increased with the implementation of SMED, TPM and KANBAN tools.

4.2. Diagnosis

The low level of service in the machine shop is influenced by operational inefficiencies and high costs. The main reasons are late deliveries of orders and after-sales complaints. The root causes of these difficulties are related to the absence of preventive maintenance plans, long changeover times due to non-standardized procedures, and a disorganized approach to inventory control, which led to critical service-level issues.The analysis revealed that unplanned activities contribute to a 65% availability of equipment. In addition, long changeover times caused by inconsistent methods contribute to 46.61% of orders not delivered on time. On the other hand, the spare parts generated by lack of management in the spare parts have an impact of 68.13% with respect to post-service claims. Thus, the low level of service represents a financial impact of PEN 219,586 of the annual turnover.

4.3. Validation Method

4.3.1. Validation Method Case

The validation process of the developed models (Figures 4 and 5) consisted of implementing two simulations using Arena simulation software. One model focused on key maintenance processes related to the application of the TPM and SMED tools, while the second addressed inventory management, supported by a pilot test of the physical Kanban board to collect data. This approach made it possible to replicate real system conditions in a controlled and small-scale environment, providing results that support the feasibility of the improvement proposal both before and after implementation.

Experimental Configuration

In order to ensure the reproducibility and validity of the simulation model, a structured data collection process was conducted. More than 50 complete vehicle repair cycles were recorded, considering only those vehicles that underwent all the stages represented in the Arena simulation flow. For each case, both process times and delays were manually measured using time-tracking sheets and synchronized stopwatches. These data served as the basis for defining the statistical distributions and average durations of each activity modeled in Arena. The Kanban system was physically implemented in the workshop as a pilot. Cards were placed on a centralized board to visually track the status of spare parts and replenishment needs. The board was located in the inventory control area and utilized color-coded signals to indicate reorder points. The pilot was monitored over a three-month period to assess its effectiveness in managing spare parts availability and reducing service delays.This experimental setup enabled the simulation to reflect realistic operating conditions, enhancing the precision and applicability of the proposed improvement model.

Table 2. Service level

Indicator	Current Value	Standard Value	Difference
Service Level	82.67%	92.2%	9.53%

Continuous monitoring of the improvement indicators was conducted to validate the proposal using real workshop data and to evaluate potential changes affecting the model. For the validation process, it was essential to document all generated data, from time measurements to spare part turnover, ensuring the reliability and feasibility of the project. The validation phase assessed the performance of each tool based on the proposed indicators and aimed to determine the overall impact and the extent of improvement achieved.

4.3.2. Arena Simulator Simulation Model

To guarantee the robustness of the model, the number of replicas to be used was calculated. For each of the models, a confidence level (Z) of 95% was considered, with a margin of error (e) of 5%. To do this, a total of 20 replicates per indicator were used to obtain the standard deviation of each of them from the input analyzer tool, as well as the distributions associated with the processes.

$$n = \left[\frac{t_{(n-1,1-\alpha/2)} * S_{(n)}}{e}\right]^2 \quad (5)$$

In the simulation model (Figures 7 and 8), the Failure module was used to represent the frequency of equipment failures, recognizing that in the base model, these failures represent 35% of the total operating time, equivalent to 33.5 lost days of productivity per year. Restrictions will also be used for pre-orders in the inventory season. Both models simulated 1 year of service in the workshop, taking into account 360 days, 8 hours of work and 10 operators. The model developed in the Arena software shows the key interactions and workflows analyzed. In the simulation model (Figures 9 and 10), the Kanban system was integrated as a visual tool for managing spare parts inventory, incorporating signaling mechanisms to control replenishment processes and prevent any stockouts. The model considered service delays and inefficiencies in vehicle turnaround time.

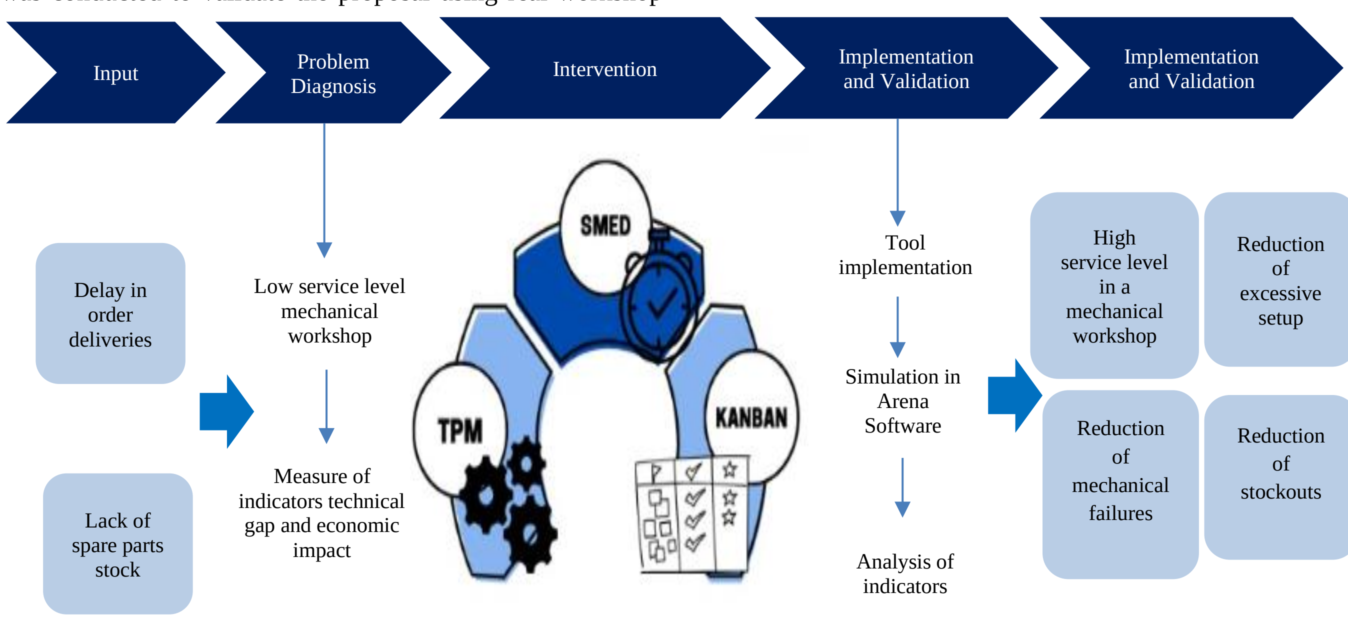

Fig. 1 Proposed model

Through the implementation of defined reorder points, it was possible to maintain a continuous flow of materials and improve inventory turnover. The simulation encompassed one year of operation. The model, developed using Arena software, captures the real-time dynamics of spare part consumption, emphasizing the role of Kanban in ensuring stock continuity through the use of advance orders strategically placed to prevent service interruptions.

4.3.3. Simulation Results

Table 3 shows the initial indicators of the system together with the values obtained after implementation. After applying the model's tools, a potential increase in the service level of the workshop was observed, as well as in the availability of machines and inventory turnover, in addition to a significant reduction in process times, such as improved inventory management. The proposed model efficiently solved problems related to a low level of service, achieving an increase of 4.98%. Equipment utilization increased considerably by 16.31%, and mechanical failures decreased by 94.34%.

$$n = \left[\frac{t_{(n-1,1-\alpha/2)} * S_{(n)}}{e}\right]^2$$

4.3.4. Economic Validation

An evaluation of the financial cash flow was carried out over 12 months, considering the expenses involved in the implementation of the proposed improvement tools. The total investment was PEN 8,975, of which 40%, corresponding to PEN 3,590, was covered with own resources, while 60%, equivalent to PEN 5,385, was financed through a bank loan.

Fig. 2 Implementation of KANBAN board and cards

The analysis showed a Net Present Value (NPV) of PEN 55,877, which supports the viability of the project, accompanied by an Internal Rate of Return (IRR) of 107.13%, far exceeding the estimated Cost of Capital by 16.15%, demonstrating high profitability. In addition, financial cash flow reflected a notable improvement, confirming the effectiveness of the measures implemented. The period needed to recover the investment was only 1.7 months, which ensures a fast and efficient return. Likewise, an annual savings of PEN 264,096 is projected, mainly thanks to the reduction of costs related to penalties, maintenance, and consumption of water and electricity. The analysis demonstrates that the improvements applied in the workshop generated significant economic and operational benefits, contributing to its financial sustainability.

5. Discussion

The simulation validated the effectiveness of the proposed model in improving the service level of the mechanical workshop through the integrated application of TPM, SMED, and KANBAN, achieving a final service level of 92.72%. This result exceeds the findings reported by Briceño et al. (2023), who observed an improvement from 84% to 91.5% in a tire repair shop [2], considering that the present study was applied to a broader process flow that includes diagnostics, disassembly, maintenance, painting, and delivery.

The model is distinguished by the simultaneous and coordinated application of three improvement tools within a single intervention framework, unlike previous studies that implement them individually. This integration enabled a total process time reduction of 35.39%, compared to the 11% setup time reduction reported in studies that applied only SMED and 5S [15]. This difference is explained by the implementation of standardized protocols, task-specific checklists, and focused operator training to convert internal activities into external ones. Equipment availability during the disassembly stage reached 75.6%, a result associated with the implementation of preventive and autonomous maintenance based on TPM pillars.

In comparison, studies in the manufacturing sector reported an increase in Overall Equipment Effectiveness (OEE) to 90.22% [15]; however, in the present study, a reduction of over 94% in mechanical failures was also achieved, attributable to detailed maintenance scheduling and the inclusion of real-time monitoring during the pilot phase. Regarding inventory management, the implementation of a physical KANBAN system prevented stockouts and improved the turnover of critical spare parts. While other studies reported reductions in penalty-related costs from 5% to 2% [2], the present study projects annual savings of PEN 264,096, associated with reduced rework and fulfillment errors. These results were made possible through the use of visual signals, the definition of minimum and maximum stock levels, and an early replenishment system adjusted to the workshop's real demand.

The results obtained demonstrate that the combined application of improvement tools, supported by real data validation and pilot testing in an operational environment, enabled superior outcomes in key performance indicators such as service level, operational availability, and economic efficiency. The positive results obtained in this case encourage further testing of the model in additional workshop environments with different operational conditions.

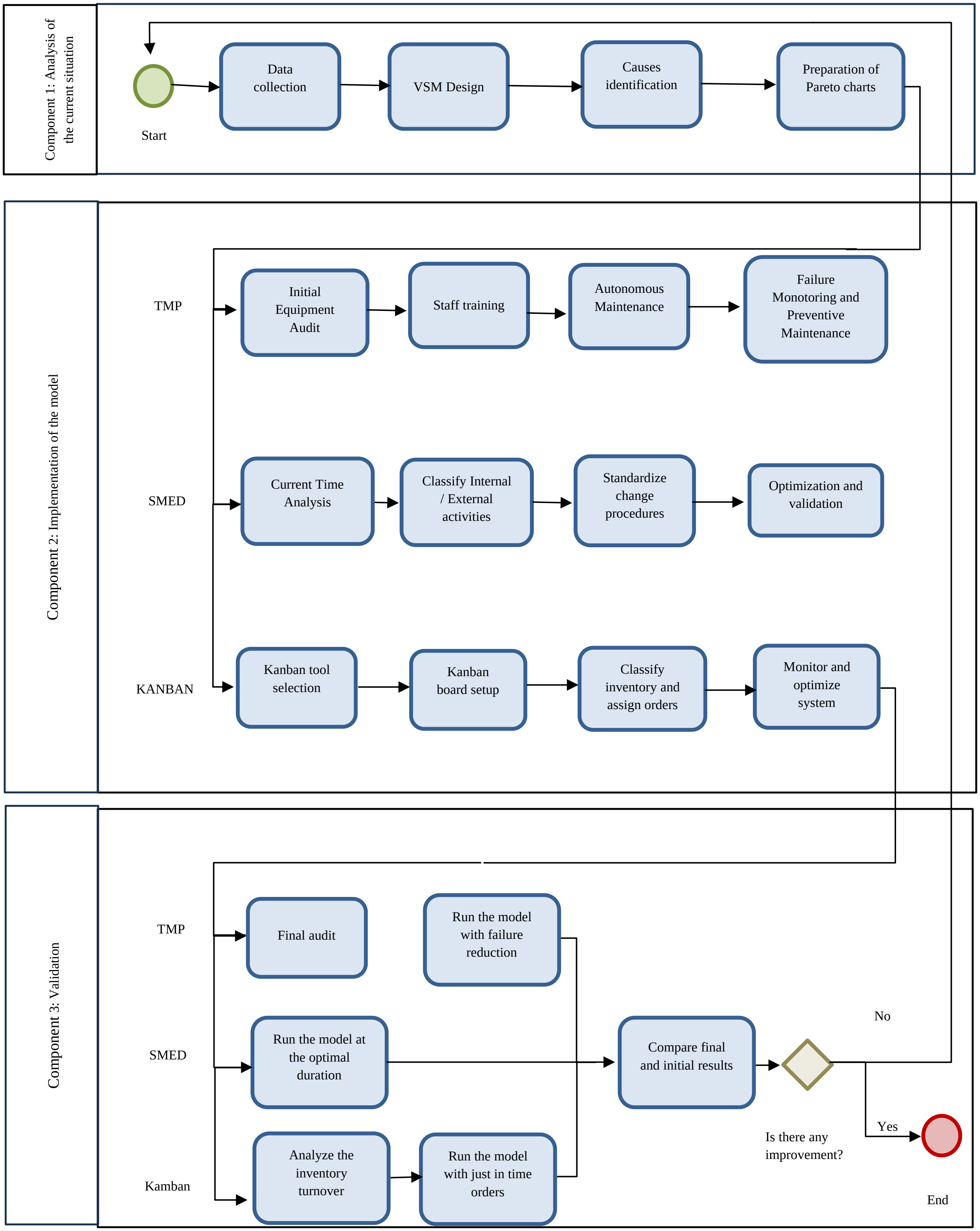

Fig. 3 Proposed method flow

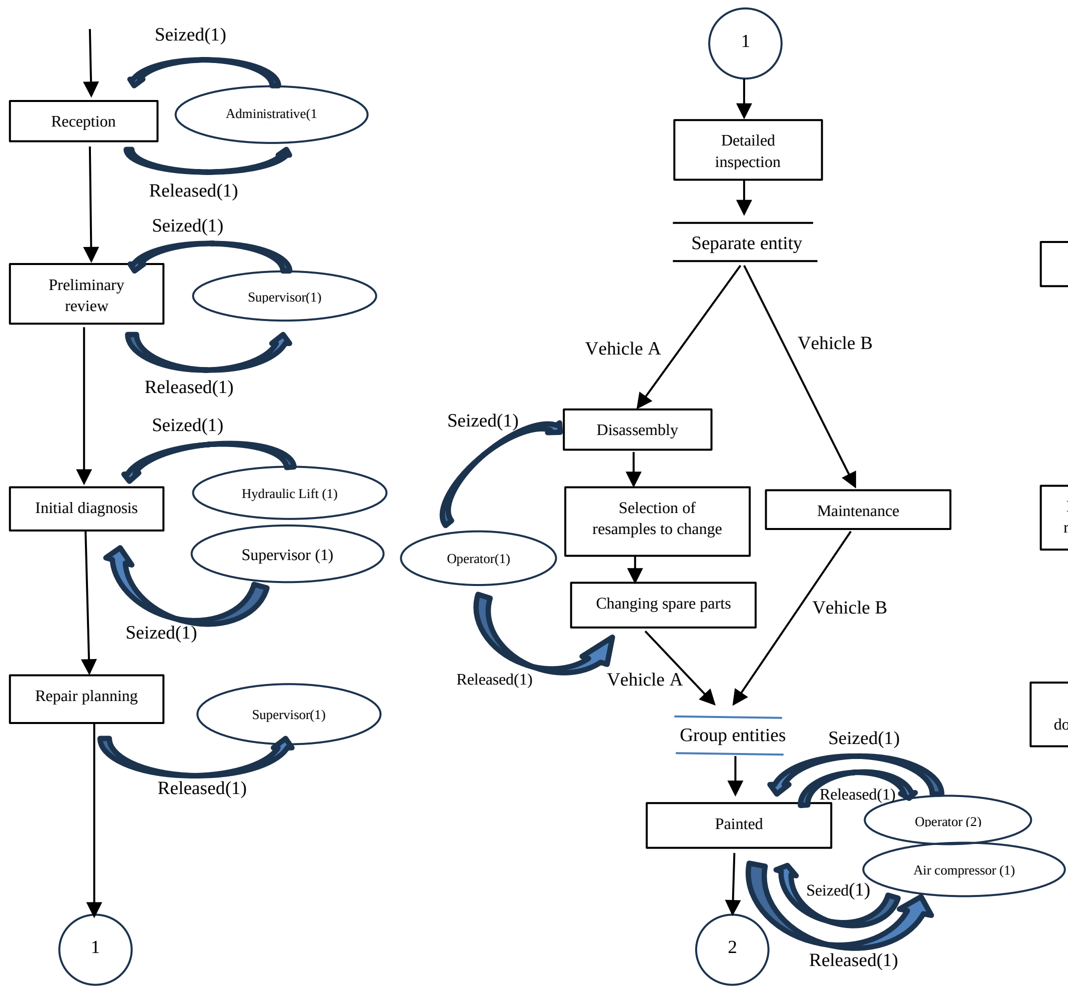

Fig. 4 Representation of the improved model with SMED and TPM

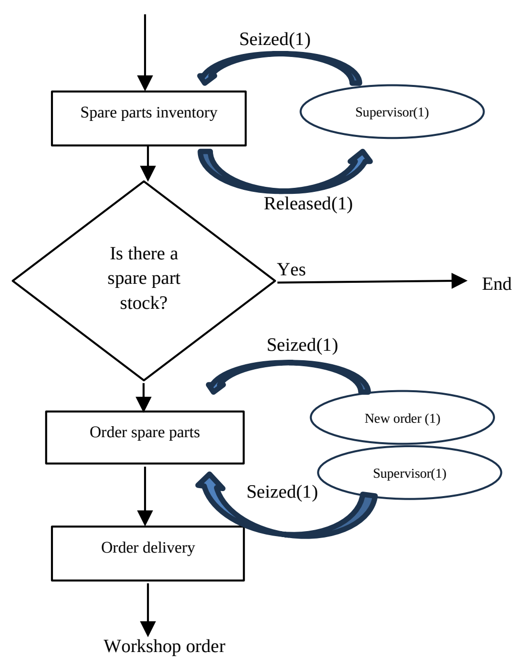

Fig. 5 Representation of the improved model with KANBAN

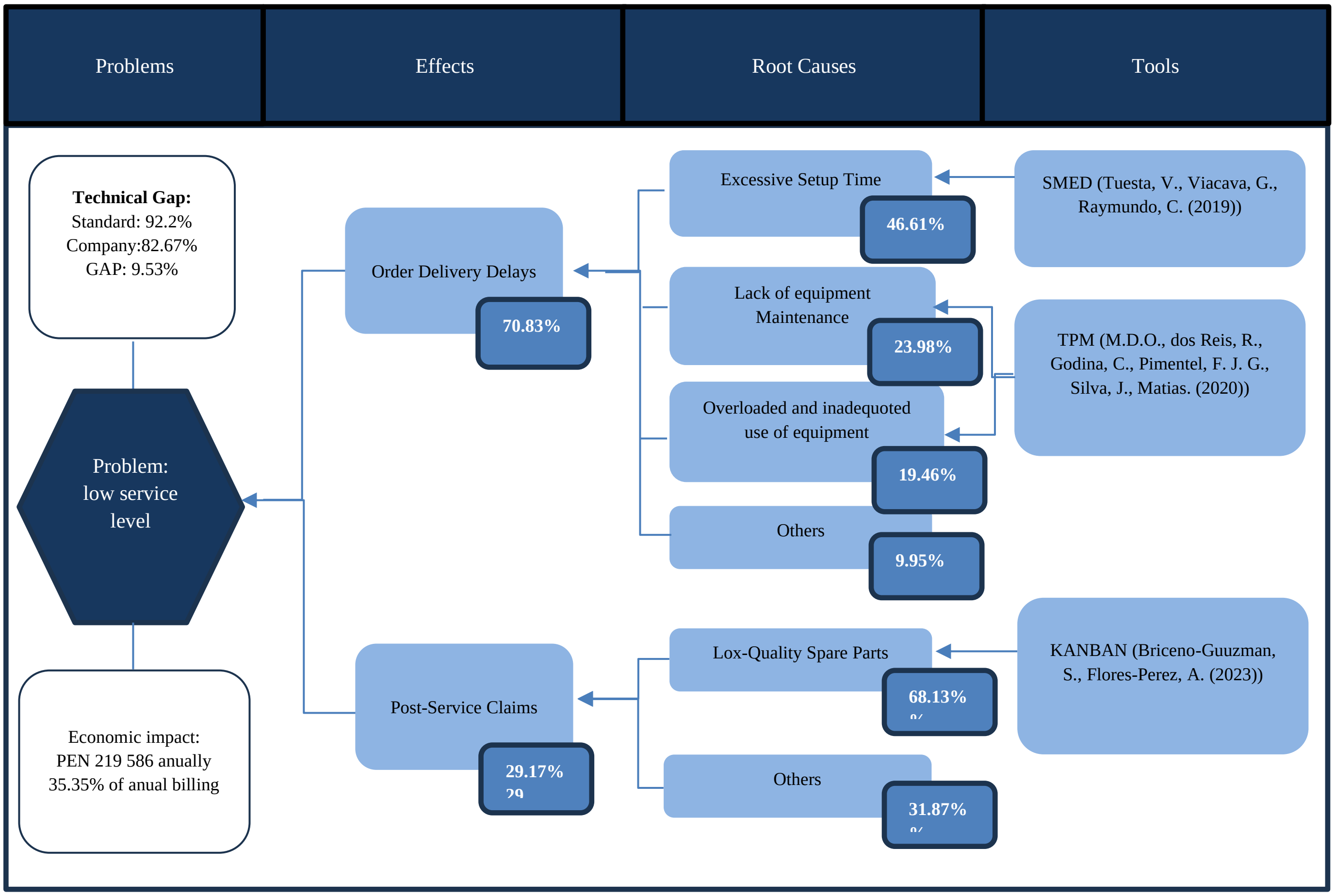

Fig. 6 Problem tree

Table 3. Validation process results

Description	As is	To Be	Variation	Original Model Results	Improved Model Results	Tools	Reference
Elevator 1 availability	65%	75,6%	16,31%	[64,5-66,1]	[74,4-75,7]	Preventive TPM	(M.D.O, dos Reis, R., Godina, C., Pimentel, F.J.G., Silva, J., Matías. (2020)
Annual mechanical failures	53	4	94,34%	[49-57]	[1-4]	Preventive and Autonomous TPM	Chaurey, S., Kalpande, S.D., Gupta, R.C., Toke, L.K. (2023)
Average vehicle stay time (Min)	356	230	35,39%	[354-359]	[229-230]	SMED	Tuesta, V., viacava, G., Raymundo, C. (2019)
Inventory turnover	0.969	1,59	64,09%	[0,916-1,02]	[1,51-1,67]	KANBAN	Ricky, C., Kadono, Y. (2020)
Number of stockouts	48	12	75%	[48,2- 48,4]	[11,168-12,344]	KANBAN	Briceno-Guzman, S., Flores-Perez, A. (2023)

Table 4. Economic indicator

Indicators	Value
Net Present Value (NPV)	PEN 55,877
Internal Rate of Return (IRR)	107.13%
B/C	7
Payback Period (Months)	1.7

5.1. Study Limitations

This study has limitations related to the predisposition of employees to change, which could hinder the implementation of improvement methodologies in other mechanical workshops. Although their effectiveness has been proven when applied properly. In addition, staff turnover could affect the continuity of improvements, as onboarding new employees requires prior training. The six-month implementation period may not be sufficient to assess the long-term effects, including changes in organizational culture.

5.2. Recommendations for Mechanical Workshops Based on Results

Start with preventive and autonomous maintenance to obtain immediate and sustainable improvements. It is crucial to train operators in autonomous tasks and standardize operational processes. Also, key metrics such as equipment efficiency and cycle times must be defined to continuously evaluate and adjust methodologies.

It is recommended to implement the Kanban system to efficiently manage inventories and avoid stock shortages. In addition, the application of SMED will reduce changeover times, improving fluidity in the entry and exit of vehicles, which will increase efficiency in repairs.

5.3. Future Works

Future research could also address the implementation of other TPM pillars beyond preventive and autonomous maintenance, particularly the Focused Improvement pillar, to identify and resolve recurring issues in critical equipment, such as hydraulic lifts. Furthermore, the integration of artificial intelligence systems to forecast the demand for spare parts and anticipate their shortage would improve efficiency in inventory management through Kanban boards. Additionally, the development of data-driven decision-making practices can contribute to a culture of continuous improvement, enabling workshops to adapt more rapidly to operational challenges.While the reliance on manual labor in the present case limited automation possibilities, in workshops where it is feasible, it is recommended to consider the partial automation of the setup processes to reduce changeover times and improve operational efficiency. It is essential to invest in the upskilling and engagement of personnel to ensure long-term sustainability.

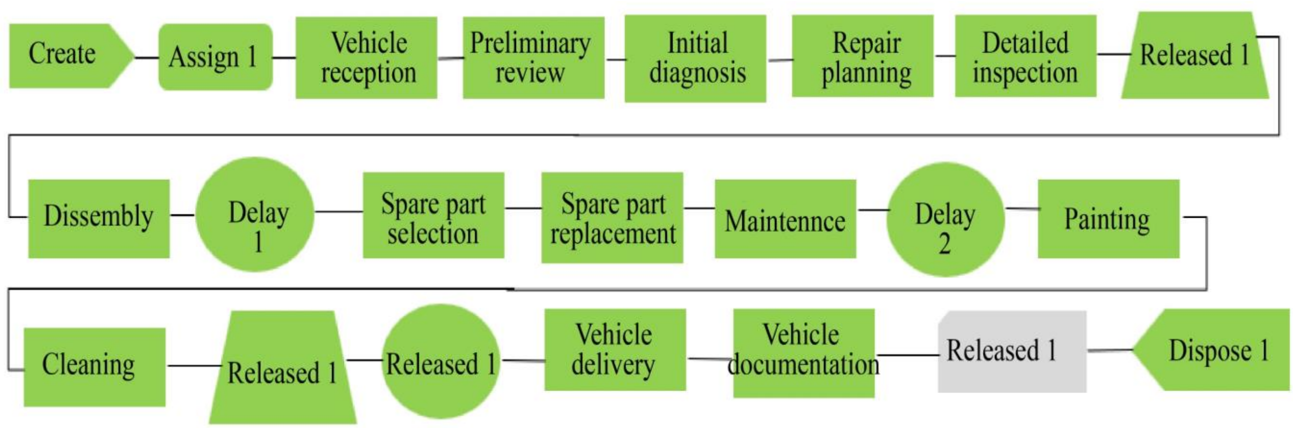

Fig. 7 Original model before the implementation of SMED and TPM tools in arena software

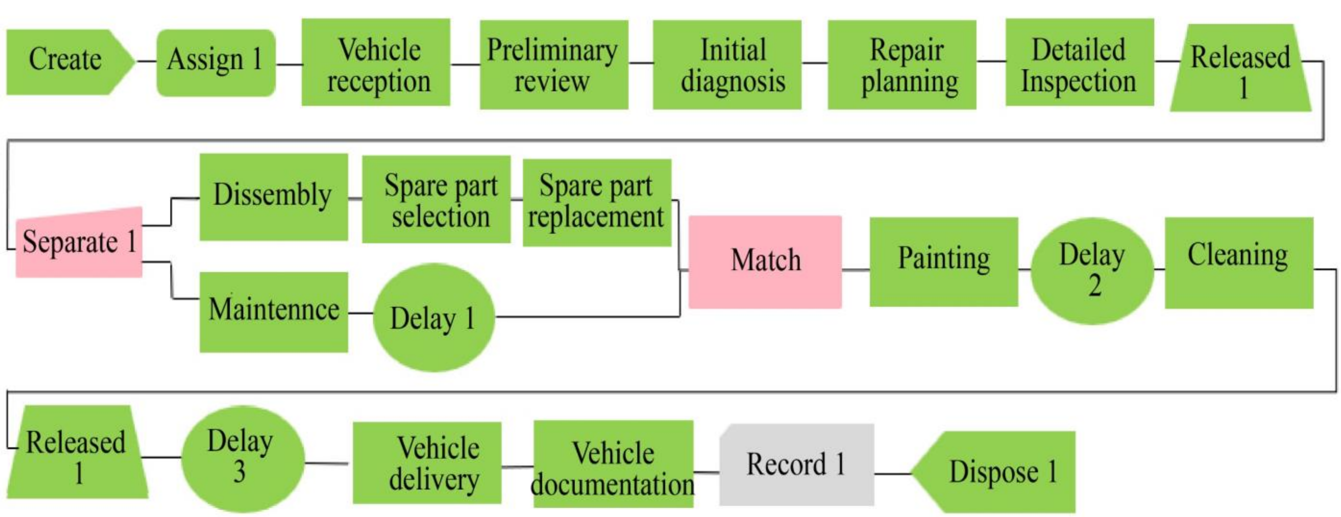

Fig. 8 Proposed model for the implementation of SMED and TPM tools in arena software

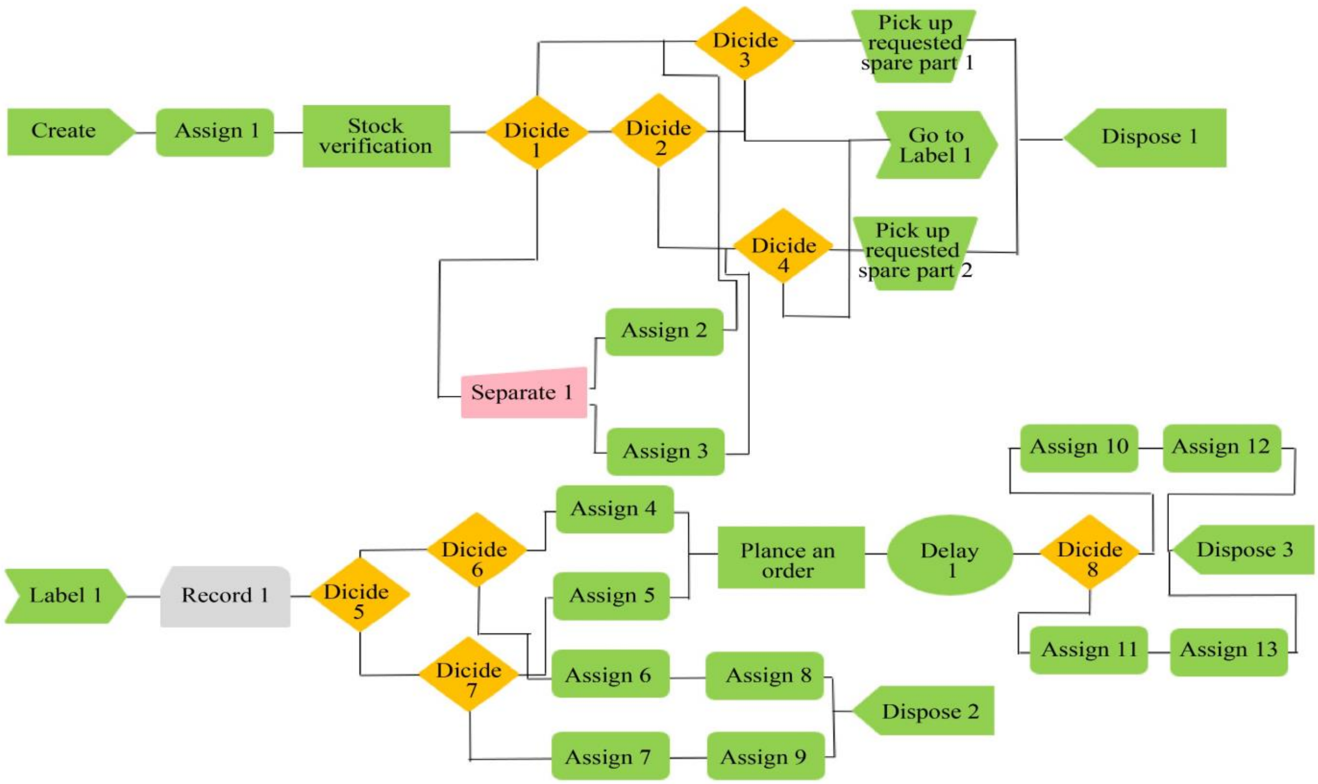

Fig. 9 Original model before the implementation of kanban tool in arena software

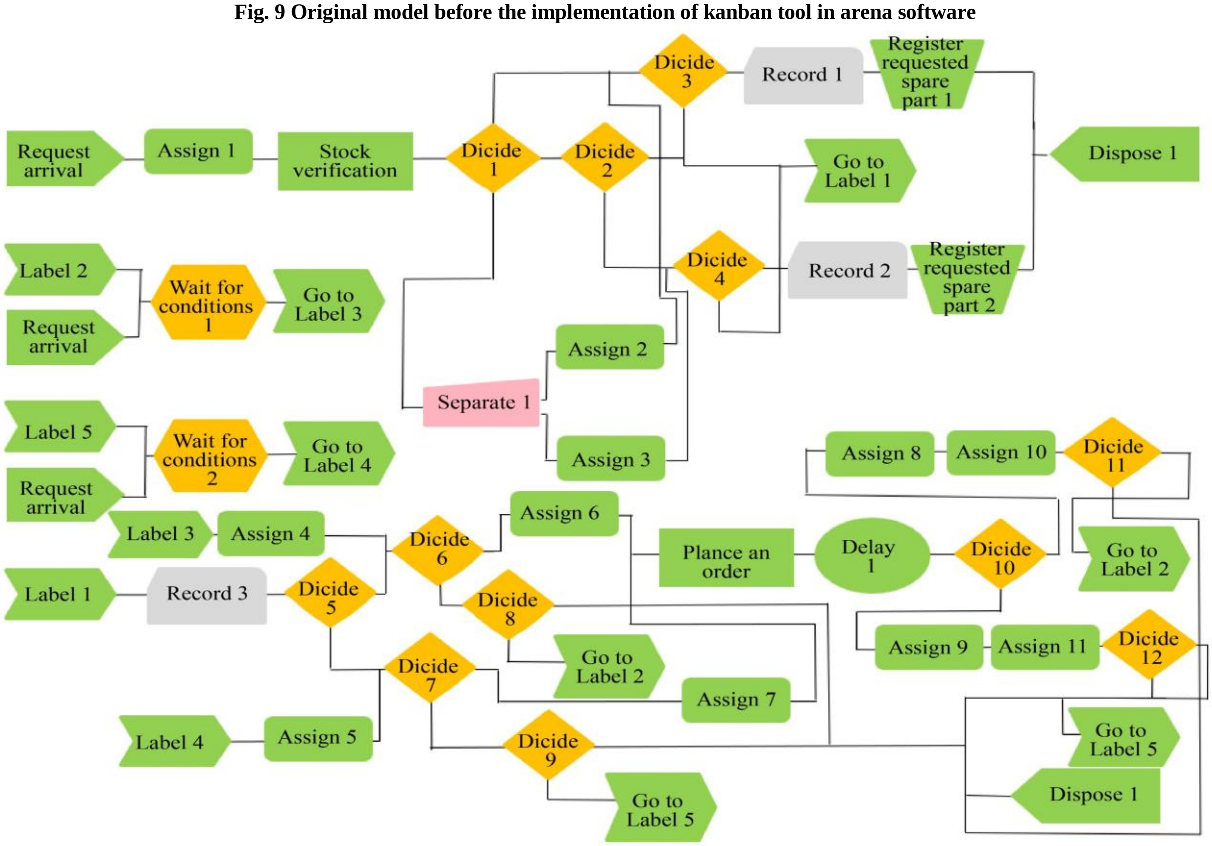

Fig. 10 Proposed model for the implementation of kanban tool in arena software

6. Conclusion

The analysis carried out made it possible to identify that the workshop faced a problem related to punctuality in deliveries and post-service complaints, directly affecting its level of service. To address this situation, an improvement model was developed and implemented based on SMED, TPM and Kanban tools, whose positive impact is reflected in the results obtained.The SMED tool achieved a significant reduction in setup times, decreasing vehicle dwell time by 35.39% and reducing orders delivered after the deadline from 68.13% to 34.10%. For its part, the implementation of TPM made it possible to reduce unplanned failures in workshop equipment, reducing failures from 70.83% to 22.78% and downtimes by 16.6%, ensuring greater operational continuity. Likewise, the application of Kanban improved inventory management, increasing turnover by 64.09% and reducing stockouts by 75%, which contributed to guaranteeing the quality of spare parts and reducing post-service complaints. In terms of overall results, the workshop's service level increased from 82.67% to 92.72%, exceeding the standard of 92.2% and strengthening customer satisfaction. This increase was accompanied by an annual saving of PEN 264,096 in operating costs, highlighting a reduction of PEN 160,466 in penalties and PEN 33,900 in maintenance costs. In addition, water and electricity costs decreased by PEN 32,955 and PEN 3,711, respectively, thanks to improvements in operational efficiency. Finally, the economic indicators in Table 4 show the viability of the project. The NPV of the model reached PEN 55,877, with an IRR of 107.13% and an ROI of 7, reflecting high profitability in relation to the investment. In addition, the payback period was reduced to 1.7 months, consolidating the economic sustainability and effectiveness of the tools applied.

References

[1] Victor Tuesta, Gino Viacava, Carlos Raymundo, "Lean Service Model to Increase the Attention Capacity of a Car Repair Shop," *Industry, Innovation, and Infrastructure for Sustainable Cities and Communities: Proceedings of the 17th LACCEI International Multi-Conference for Engineering, Education and Technology*, Montego Bay, Jamaica, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[2] Sebastian Briceno-Guzman, Paulo Mejia-Pilco, and Alberto Flores-Perez, "Reduction of Delays in Rim Repairs using Lean Service Tools in an Automotive Workshop in Lima," *ICIEAEU '23: Proceedings of the 2023 10th International Conference on Industrial Engineering and Applications*, Rome, Italy, 2023. [CrossRef] [Google Scholar] [Publisher Link]

[3] Maria Afonso, Ana Teresa Gabriel, and Radu Godina, "Proposal of an Innovative Ergonomic SMED Model in an Automotive Steel Springs Industrial Unit," *Advances in Industrial and Manufacturing Engineering*, vol. 4, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[4] A.M. Vieira et al., "SMED Methodology Applied to the Deep Drawing Process in the Automotive Industry," *Procedia Manufacturing*, vol. 51, pp. 1416-1422, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[5] Julia C. Arlinghaus, and Stephanie Knizkov, "Lean Maintenance and Repair Implementation - A Cross-Case Study of Seven Automotive Service Suppliers," *Procedia CIRP*, vol. 93, pp. 955-964, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[6] Arturo Chávez et al., "Implementation of an Improvement Plan to Reduce the Operating Costs of a Manufacturing Company," *20th LACCEI International Multi-Conference for Engineering, Education and Technology, Education, Research and Leadership in Post-pandemic Engineering: Resilient, Inclusive and Sustainable Actions*, Hybrid Event, Boca Raton, Florida- USA, pp. 1-10, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[7] M.D.O. dos Reis et al., "A TPM Strategy Implementation in an Automotive Production Line Through Loss Reduction," *Procedia Manufacturing*, vol. 38, pp. 908-915, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[8] Marko Zlatić, "Tpm - Total Productive Maintenance," *Proceedings on Engineering Sciences*, vol. 1, no. 2, pp. 581-590, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[9] Tomé Pombal et al., "Implementation of Lean Methodologies in the Management of Consumable Materials in the Maintenance Workshops of an Industrial Company," *Procedia Manufacturing*, vol. 38, pp. 975-982, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[10] E. Á. Fuentes y A. Rojas, "Standardization of Operations in the After-Sales Service of an Automotive Company for the Main Brand," *Información tecnológica*, vol. 29, no. 4, pp. 189-196, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[11] Zainil Hanim Saidin et al., "The Impact of Automotive After-Sales Service Quality and Alternative Attractiveness on Customer Loyalty," *International Journal of Supply Chain Management*, vol. 7, no. 1, pp. 177-188, 2018. [Google Scholar] [Publisher Link]

[12] John Aiyesehinde, and Clinton Aigbavboa, "Identifying the Critical Factors Driving the Quality of After-Sales Services in the Nigerian Automotive Industry," *2019 IEEE AFRICON*, Accra, Ghana, pp. 1-5, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[13] Jorge Arnoldo Valencia Granados, "Importance of measuring Service Level or Fill Rate in Modern Logistics," *Realidad Empresarial*, no. 10, pp. 75-78, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[14] I. M. Ribeiro et al., "Implementing TPM Supported by 5S to Improve the Availability of an Automotive Production Line," *Procedia Manufacturing*, vol. 38, pp. 1574-1581, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[15] G.F.L. Pinto et al., "Continuous Improvement in Maintenance: A Case Study in the Automotive Industry Involving Lean Tools," *Procedia Manufacturing*, vol. 38, pp. 1582-1591, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[16] Marc Martins et al., "A Practical Study of the Application of SMED to Electron-Beam Machining in Automotive Industry," *Procedia Manufacturing*, vol. 17, pp. 647-654, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[17] Miranda-López, Yrwing, Toledo-Loza, Fiorella, and Altamirano Flores, Ernesto, "Optimization Model to Increase the Efficiency of the Flexible Packaging Production Process Applying the Johnson Method, SMED and TPM in a SME in the Plastics Sector," *20th LACCEI International Multi-Conference for Engineering, Education, and Technology: "Education, Research and Leadership in Post-pandemic Engineering: Resilient, Inclusive and Sustainable Actions,"* Hybrid Event, Boca Raton, Florida- USA, pp. 1-8, 2022. [CrossRef] [Publisher Link]

[18] Christian Ricky, and Yasuo Kadono, "A Case Study of E-Kanban Implementation in Indonesian Automotive Manufacture," *2020 8th International Conference on Cyber and IT Service Management (CITSM)*, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[19] S. Magnus Ågren et al., "The Impact of Requirements on Systems Development Speed: A Multiple-Case Study in Automotive," *Requirements Engineering*, vol. 24, no. 3, pp. 315-340, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[20] S. Magnus Ågren et al., "The Manager Perspective on Requirements Impact on Automotive Systems Development Speed," *2018 IEEE 26th International Requirements Engineering Conference (RE)*, Banff, AB, Canada, pp. 17-28, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[21] Muhammad Zubair Alam et al., "Drivers and Challenges of Tacit Knowledge Sharing in Automotive Workshop Employees," *VINE Journal of Information and Knowledge Management Systems*, vol. 52, no. 1, pp. 71-86, 2020. [CrossRef] [Google Scholar] [Publisher Link]

[22] Iris Bento da Silva et al., "Lean Six Sigma for the Automotive Industry Through the Tools and Aspects Within Metrics: A Literature Review," *The International Journal of Advanced Manufacturing Technology*, vol. 119, no. 3-4, pp. 1357-1383, 2021. [CrossRef] [Google Scholar] [Publisher Link]

Appendix

Table 1. Comparative table of the components of the Proposal Model vs the Literature review

○ = unfulfilled ◑ = partially fulfilled ● = completely fulfilled	Lean Service Model to Increase the Service Capacity of an Automotive Workshop **Case:** Standardization of the Drying Process		Reduction of delays in rim repairs using Lean Service tools in an automotive workshop in Lima. **Case:** Tire Repair in a Vehicle		A TPM strategy implementation in an automotive production line through loss reduction. **Case:** Reduction of Losses Caused by Machine Failures		SMED methodology is applied to the deep drawing process in the automotive industry. **Case:** Increasing the Availability of a Deep Drawing Machine		Identifying the critical factors driving the quality of After-sales services in the Nigerian automotive industry. **Case:** Critical Factors Driving the Quality of Automotive Services		Implementing TPM supported by 5S to improve the availability of an automotive production line. **Case:** Improving the Availability of a Production Station in the Mechanical Workshop		Improvement of Service Levels Using SMED, TPM, and KANBAN Tools in a Mechanical Workshop **Case:** Reducing Vehicle Delivery Delays and Improving Service Quality	
	Tuesta, V., Viacava, G., & Raymundo, C. (2019)		Briceno-Guzman, S., Mejia-Pilco, P., & Flores-Pérez, A. (2023)		Reis, M. D., Godina, R., Pimentel, C., Silva, F., & De Oliveira Matias, J. C. (2019)		Vieira, A. M. P. D. R., Silva, F., Campilho, R., Ferreira, L. P., Sá, J. C., & Pereira, T. (2020)		Aiyesehinde, J., & Aigbavboa, C. (2019)		Ribeiro, I. M., Godina, R., Pimentel, C., Silva, F., & Matias, J. C. O. (2019)		Montes-Cabrera,A., Gherardi-Jiménez,F., Quiroz-Flores,J. (2024)	
Component 1 Diagnosis Problem **<u>Literature Review:</u>** • **Engineering Tool:** Value Stream Mapping (VSM), Ishikawa Diagram, Pareto Diagram. • **Case Study:** Service Level Improvement. • **Metric:** Reduction of setups, unplanned mechanical failures, availability, inventory turnover,	Literature review	●	Literature review	●	Literature review	○	Literature review	●	Literature review	◑	Literature review	○	Literature review	●
	Engineering tool	◑	Engineering tool	◑	Engineering tool	●	Engineering tool	◑	Engineering tool	○	Engineering tool	◑	Engineering tool	●
	Case study	○	Case study	●	Case study	○	Case study	○	Case study	◑	Case study	○	Case study	●
	Metrics	●	Metrics	●	Metrics	●	Metrics	◑	Metrics	○	Metrics	●	Metrics	●

stockouts														
Component 2: Identification and Implementation of Tools **<u>Literature Review:</u>** • **Engineering Tool:** SMED, TPM, KANBAN • **Case Study:** Service Level Improvement. • **Metric:** Reduction of setups, unplanned mechanical failures, availability, inventory turnover, stockouts	Literature review	●	Literature review	○	Literature review	○	Literature review	○	Literature review	●	Literature review	◑	Literature review	●
	Engineering tool	◑	Engineering tool	●	Engineering tool	●	Engineering tool	●	Engineering tool	○	Engineering tool	◑	Engineering tool	●
	Case study	○	Case study	◑	Case study	◑	Case study	○	Case study	◑	Case study	○	Case study	●
	Metrics	●	Metrics	●	Metrics	●	Metrics	◑	Metrics	○	Metrics	●	Metrics	●
Component 3: Validation **<u>Literature Review:</u>** • **Engineering Tool:** Simulation • **Case Study:** Service Level Improvement. • **Metric:** Reduction of setups, unplanned mechanical failures, availability, inventory turnover, stockouts	Literature review	○	Literature review	○	Literature review	○	Literature review	○	Literature review	●	Literature review	○	Literature review	●
	Engineering tool	○	Engineering tool	●	Engineering tool	◑	Engineering tool	○	Engineering tool	○	Engineering tool	○	Engineering tool	●
	Case study	●	Case study	◑	Case study	○	Case study	○	Case study	●	Case study	○	Case study	●
	Metrics	●	Metrics	●	Metrics	●	Metrics	◑	Metrics	○	Metrics	●	Metrics	●