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Decrease the Level of Complaints in a Company of Air Compressors through Lean Manufacturing Based On Dmaic Methodology

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Abstract - In the field of mining and construction, the machinery and equipment subsector face challenges in customer service quality due to repeated reprocessing caused by a lack of preventive maintenance. This research proposed a solution based on Lean Manufacturing by applying Total Productive Maintenance (TPM), following the steps of a DMAIC methodology, and conducting simulations using Arena software. The initiative focused on streamlining the rental process, reducing response times, and improving the reliability of compressors. Positive outcomes were anticipated, including increased equipment availability, reduced response times, a decrease in the failure rate, and improved customer satisfaction. Furthermore, simulation results revealed a significant transformation: the average customer service time decreased by 35.49% (from 1714.70 to 1106.03 minutes), and the average preparation time of a compressor before rental decreased by 32.81% (from 2750.53 minutes to 1847.86 minutes). In the economic analysis, the feasibility of the proposal was demonstrated using @risk software, with a Net Present Value (NPV) of $139,024 and an Internal Rate of Return (IRR) of 34.83%, surpassing the Cost of Capital (COK). This research aimed not only to enhance key performance indicators but also to position the company as a leader in efficiency and customer satisfaction in the competitive machinery and equipment sector. This holistic approach not only strengthened operational efficiency and cost reduction but also contributed to the sustainable development of the machinery and equipment sector.

Keywords: Lean Manufacturing, TPM (Total Productive Maintenance), DMAIC (Define, Measure, Analyze, Improve, Control), Air Compressors, Customer Satisfaction.

1. Introduction

In the context of the Peruvian economy, the mining and construction sector plays a fundamental role, representing a percentage of 3% in the country's Gross Domestic Product (GDP). According to data from the Ministry of Energy and Mines, this sector substantially contributes to the national economic development, serving as a cornerstone in the execution of projects that drive growth and infrastructure. The use of air compressors for such projects is crucial. According to Atlas Copco (2021), screw-type air compressors are the most widely used in the industrial market, providing continuous compressed air for precision work and being extremely efficient and quiet. However, industries have been affected by reprocessing and the resulting consequences. According to ISO 9000 standards, reprocessing is an action taken on a non-conforming product to make it meet the requirements. This leads to a deficiency in customer service levels, as it brings about a significant increase in costs and times, claims for non-compliance, and even loss of customers. It not only can be an economic loss for the company but also can have a negative impact on the company's image.

In this context, a case study was conducted at Chang SAC, focusing on the most significant causes of the deficiency in service levels in the sector: unsatisfactory compressor performance and issues in technical service. For the development of this solution, Lean Manufacturing was applied using a DMAIC methodology.

2. State of the art

The Lean Manufacturing approach, based on the DMAIC methodology, positively impacts the research by addressing service quality challenges in a company engaged in the rental and sale of screw-type air compressors in the mining and construction industry.

2.1 Lean Manufacturing (TPM)

In the research on Chang SAC, Lean Manufacturing emerges as a management tool that helped maximize value for the customer by eliminating waste and optimizing processes. It focused on streamlining the rental process, reducing response times, and enhancing the reliability of screw-type air compressors. This tool drove operational efficiency by eliminating unnecessary activities, reducing rework, improving customer service quality, and facilitating preventive diagnostics through Total Productive Maintenance (TPM), as stated by Hernandez (2013).

2.2 Work Standardization

"Work standardization" is a pivotal component of Lean Manufacturing involving the establishment of uniform and efficient procedures in operations. By implementing standardized processes, the aim is to reduce variability, enhance consistency in operations, and facilitate the identification of potential improvements. This directly contributes to efficiency, service quality, and resource optimization—essential elements for achieving the proposal's objectives. As emphasized by Carlson, Peterson, and Norman (2009), work standardization plays a crucial role in Lean Manufacturing by reducing variability and enhancing operational efficiency.

2.3 Analysis and Evaluation of Organization's Key Performance Indicators (KPIs)

Key Performance Indicators (KPIs) played a crucial role in measuring the efficiency and effectiveness of the company, Marr (2012) provides insights into the analysis and evaluation of Key Performance Indicators (KPIs) as essential tools for measuring organizational performance and driving improvement initiatives.

Table.1 Company Performance Indicators

Tool	Indicator	Current Value	Expected Value	% improvement
Work Standardization	Claim Rate = Total Claims / Total Orders	15%	10%	33.33%
	Claim Response Time = Claim Arrival Time - Service Time	1.5 hours (90 minutes)	1 hour (60 minutes)	33.33%
	Net Promoter Score (NPS)	-30%	50%	266.67%
TPM	Equipment Availability = (Available Time for Renting / Total Time) x 100	Small-capacity equipment: 85%. Medium-capacity equipment: 70%. Large-capacity equipment: 80%.	Small-capacity equipment: 95%. Medium-capacity equipment: 80%. Large-capacity equipment: 85%.	Small-capacity equipment: 11.76%. Medium-capacity equipment: 14.29%. Large-capacity equipment: 6.25%.
	Maintenance Efficiency = (Actual Operating Time / Total Available Time) x 100	60%	80%	33.33%

Table.1 shows that for work standardization, improvement objectives were set at 30% for the complaint rate, 30% for the complaint response time, and a target of a 266.67% increase in the Net Promoter Score (NPS). Regarding TPM, the goal was to enhance Equipment Availability with specific objectives for different compressor capacities. Additionally, a 33.33% improvement target was established for Maintenance Efficiency. These indicators and expected values provided a quantitative guide for evaluating the impact of the implemented improvement strategies.

2.4 Problem Identification and Root Cause Analysis

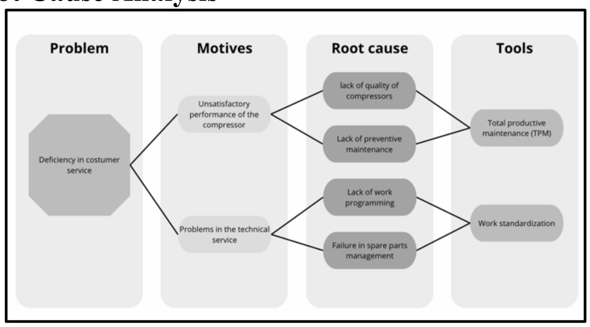

Figure 1: Cause-Linkage Diagram with Tools

The identification of issues in the air compressor rental company revealed a significant deficiency in customer service. Andersen and Fagerhaug (2006) present methodologies for problem identification and root cause analysis, crucial steps in Lean Manufacturing, to identify and address underlying issues affecting organizational performance. The primary causes identified were the unsatisfactory performance of compressors and issues in technical service. Regarding compressor performance, root causes included the lack of compressor quality and a lack of preventive maintenance. The proposed solution tool was the implementation of Total Productive Maintenance (TPM). As for issues in technical service, root causes included the lack of work scheduling and spare parts management. The recommended solution tool was work standardization. These problem identifications and root causes provided a clear foundation for the implementation of specific strategies aimed at improving customer service quality in the company.

3. Proposed Model

3.1 Components of the Model

In this study, we will leverage the DMAIC (Define, Measure, Analyze, Improve, and Control) model as elucidated by George (2003). This structured approach for process improvement, particularly tailored for service industries, is renowned for its efficacy in propelling continuous improvement initiatives. By employing this model, we aim to methodically identify, measure, analyze, improve, and control key processes within our organization, ultimately enhancing efficiency and driving sustainable progress.

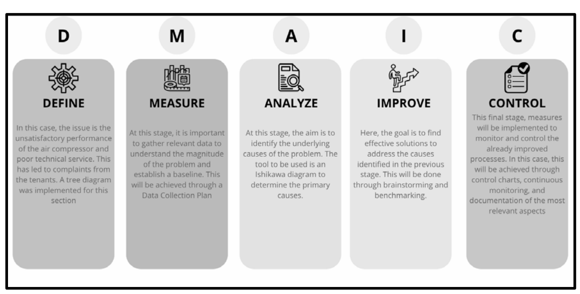

Figure 2: DMAIC Diagram

3.1.1 Define

The identified problem is the unsatisfactory performance of air compressors and inadequate technical service, leading to complaints from lessees. The objective was to reduce the complaint rate from 10% to the industry standard of 5%. A total economic impact of $140,000 annually was estimated, considering operational costs, lost opportunity costs, and penalties.

3.1.2 Measure

To comprehend the magnitude of the problem, a data collection plan was implemented. The company has a technical gap of 5%, with 10 units repaired monthly, a productivity rate of 0.0034 units repaired per labor-hour, and a cycle time of 16.97 hours per repaired unit. Additionally, fines of $5,000 annually are incurred due to delays in equipment delivery.

3.1.3 Analyze

An Ishikawa diagram was utilized to identify the underlying causes of the problem. Primary causes include technical gaps in the repair process, unplanned downtime, and additional costs due to maintenance processes.

3.1.4 Improve

In this stage, effective solutions were sought to address the identified causes. Brainstorming and benchmarking were implemented to propose improvements in the efficiency of the repair process, reduction of downtime, and optimization of maintenance costs.

3.1.5 Control

In the final stage, measures were implemented to monitor and control the improved processes. Control charts, continuous monitoring, and relevant documentation were used to ensure the sustainability of improvements and prevent the recurrence of problems.

4. Simulation and experimental results

4.1 Simulation

The chosen methodology for project validation was simulation using Arena Software. Four simulations were conducted: two representing the current state of the company in the customer service area for machinery rental and in the maintenance area, and two simulations of the project to be implemented in the same aforementioned areas after the improvement had already been implemented.

In the optimistic compressor maintenance model, as shown in Figure.3, basic maintenance and repairs are replaced by preventive maintenance.

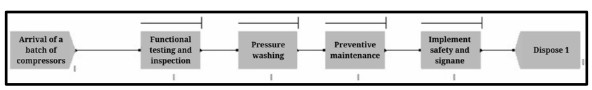

Figure 3: Optimistic Model of Compressor Maintenance

In the optimistic customer service model, as shown in Figure.4, the same processes as those existing in the company currently are maintained; however, response times are reduced.

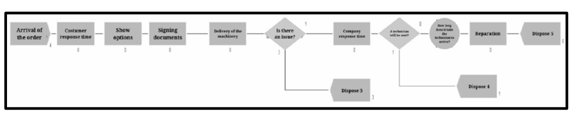

Figure 4: Optimistic Customer Service Model

4.2 Results

After conducting the simulations, a comparison was made between the current times managed by the company and the times that would be achieved with the project implementation.

In terms of the average customer service time, there was a decrease of 608 minutes with the project implementation, reducing response times. This is crucial for the company, as the reduction in times will improve customer satisfaction, operational efficiency, competitiveness, and customer retention.

Average current time	Average project time
1714.70 minutos	1106.03 minutos

Figure 5: Average Customer Service Time

Regarding customer response time, a significant decrease in response times was observed, achieving a reduction of 44 minutes.

Current customer response time	Projected customer response time
64 minutos	20 minutos

Figure 6: Customer Response Time in the Customer Service Area

In the average preparation time of a compressor, there was a decrease of 903 minutes with the project implementation. Adding preventive maintenance helped reduce unplanned downtimes caused by relying solely on basic maintenance as machinery preparation.

Current average time	Project average time
2750.53 minutos	1847.86 minutos

Figure 7: Average Preparation Time of a Compressor Before Rental

A cash flow statement was created to project the financial viability of implementing the proposal. A model incorporating probability distributions to represent uncertainty in key variables through @risk was used. The resulting NPV is $139,024 with an IRR of 34.83%.

		Year 0	Year 1	Year 2
Revenue ($)				
Opportunity cost			222,544	222,544
Fixed Costs			42,300	42,300
Adequate Personnel			30000	30000
Associated Cost			7,000	7,000
Operating Income			143,244	143,244
Taxes	30%		-42,973	-42,973
Net Income			100,271	100,271
Net Cash Flow			100,271	100,271
Initial Investment		-35,000		
Investment Financing		-35,000	0	0
Free Cash Flow		**-35,000**	**100,271**	**100,271**
Discount Rate	10%			
Present Value		-35,000	91,155	82,869
Net Present Value		**139,024**		
		139,024	139,024	
IRR (Internal Rate of Return)		**34.83%**		

Figure 8: Free Cash Flow

4.3 Relationship between KPIs - results

Table.2 compares the initial and expected KPIs, as well as the simulation results after project implementation. It clearly shows improvements in key indicators, highlighting the project's effectiveness in reducing times and improving customer satisfaction. The NPV and IRR demonstrate the financial viability of the project.

Table.2 Company Performance Indicators

KPIs	**Initial Value**	**Expected Value**	**Simulation Results (based on Initial Value)**	**Expected Improvement percentage**	**Achieved Improvement Percentage**
Complaint Response Time (hours)	1.5 hours	1 hour	44 minutes (46 minutes less)	33.33%	48.89%
Customer Service Time (minutes)	1714.70 minutes	1500 minutes	1106.03 minutes (608 minutes less)	12.5%	35.44%
Customer Response Time (minutes)	64 minutes	30 minutes	20 minutes (44 minutes less)	53.13%	68.75%
Compressor Preparation Time (minutes)	2750.53 minutes	2000 minutes	1847.86 minutes (903 minutes less)	27.28%	32.80%

It is evident that the implementation of Lean Manufacturing based on the DMAIC methodology has had a positive impact on operational efficiency and customer satisfaction.

5. Discussion

The implementation of Lean Manufacturing using the DMAIC methodology in the air compressor rental company has demonstrated substantial improvements in key performance indicators, such as a significant reduction in claims rate, response time to claims, and enhancement in customer satisfaction. These results align with the literature emphasizing the success of Lean Manufacturing in similar sectors.

Simulations not only support the achievement of specific proposed objectives but also show positive financial impacts, evidenced by the Net Present Value (NPV) and Internal Rate of Return (IRR). This finding indicates that the adopted strategy not only optimizes operational efficiency but also contributes significantly to the financial viability of the company.

In response to specific objectives, the results indicate substantial success in reducing operational times and improving customer satisfaction, validating the effectiveness of the implemented strategy to address identified issues in technical service.

When contrasting these results with the literature, the relevance of Lean Manufacturing in the specific context of air compressor rental and sales is reinforced. The comparison with the referenced research offers a comprehensive perspective. Calderón and Requejo provide valuable information on reciprocating compressor failures, while Duan et al.'s research on vibration-based fault diagnosis enriches the understanding of implemented improvements. Zahedi et al.'s thesis on production optimization and maintenance scheduling provides relevant insights for operational efficiency.

Collectively, these findings validate the effectiveness of the implemented strategy, suggesting opportunities for future research and a deeper understanding of challenges and solutions in the management of compressors and technical services.

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