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Reduction in Plant Downtime by Applying Lean Manufacturing Methodology's Value Stream Mapping (VSM) and Single-Minute Exchange of Die (SMED)

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ABSTRACT

This research was conducted in a farinaceous products company that was facing a problem of low productivity due to frequent downtime, leading to underutilization of their capacity. The lean manufacturing methodology was used to address this issue, specifically value stream mapping (VSM) and single-minute exchange of die (SMED) tools. These tools were applied in stages, including a diagnostic pretest (current map), followed by design, implementation, and a posttest (final map). The results were evaluated after the completion of the process, and it was found that the application of SMED led to a significant reduction in downtime. The product changeover time was decreased from 82 minutes to 42 minutes, reducing plant downtime or waste by 40 minutes and improving lean manufacturing indicators.

Keywords: productivity, lean manufacturing, continuous improvement, waste.

INTRODUCTION

To stay competitive in the market, companies must reinforce and maintain high productivity levels, which involves designing and creating new products and processes. To increase profitability, companies must focus on their corporate culture, strategy, organization, and management style. This requires effective leadership and commitment from management, which have a direct influence on the behavior of company members (González & Michelena, 2000).

It is the responsibility of the management to create a culture of innovation within the corporation that helps identify the internal and external factors that affect the innovation process in pursuit of business prospects (Robayo, 2016).

The company under study operates in the food industry, specifically in the production of wheat-based products. It aims to achieve established objectives and goals while ensuring the continuity of the process during pre-mixing.

This research aims to determine the effectiveness of the lean manufacturing methodology's value stream mapping (VSM) and single-minute exchange of die (SMED) to increase productivity in the pre-mixing manufacturing plant by reducing plant downtime.

Additionally, the study intends to demonstrate how the application of VSM and SMED can reduce unnecessary plant downtime and increase plant production capacity.

This research provides valuable knowledge that can be used by industrial and service organizations to learn how to identify, analyze, and eliminate or reduce the root causes of time waste and, consequently, improve productivity.

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Hypothesis

The implementation of the lean manufacturing VSM and SMED techniques has resulted in significantly lower plant downtime compared to before applying the methodology.

Strategies to ensure the creation of valid and reliable knowledge that can help reduce downtime in the pre-mixing manufacturing plant will be applied in this research.

The study gathered information by mapping the current state followed by the analysis, diagnosis, and proposal of improvement measures. In this case, the farinaceous products company experienced frequent plant downtime, leading to the plant operating below full capacity, as shown in Table 1.

Table 1. *Pareto of Plant Downtime.*

Activity	%	Cumulative (%)
Load materials	53%	53%
Clean equipment	30%	83%
Mechanical failure	5%	88%
Lack of personnel	4%	92%
Lack of supplies	4%	96%
Electrical failure	2%	98%
Maintenance	2%	99%
Inventory	1%	100%

Source: Prepared by the author.

Competitiveness

Because of the increasingly complicated and demanding needs of today's market, organizational managers value competitiveness to gain an advantage and ensure the long-term viability of their organizations. The relationship between intangible assets, quality, and motivation of human resources is now highly valued, making managerial leadership crucial (Díaz et al. 2021).

Productivity Assessment

Productivity refers to the measure of how efficiently the company's resources are used (Heizer & Render, 2009).

Lean Manufacturing

Lean manufacturing is a methodology that aims to reduce or eliminate waste and all procedures that do not add value or improve product or service quality (Cuatrecasas et al., 2009; Romero, 2007). By reducing waste, productivity increases (Padilla, 2010). The benefits of implementing lean manufacturing in an organization are patent and have been demonstrated (Hernández & Vizán, 2013).

It is important to understand that lean manufacturing involves all areas of the organization, focusing on identifying activities that add value and continuous improvement (Bautista et al., 2010).

Benefits of Lean Manufacturing

Lean manufacturing is a process that offers many benefits, including the reduction of waste such as overproduction, waiting time, transportation waste, process, inventory, superfluous movements, and poor quality (Bautista et al., 2010).

Lean Manufacturing Indicators

The company's traditional performance and time indicators are supplemented with lean time and performance indicators (Reyes, 2002).

Lean Manufacturing Principles

To successfully implement lean manufacturing, a company must change its way of thinking. This requires defining the product's value, identifying the value stream, ensuring a continuous flow of value, allowing the customer to tool the product, and striving for perfection (Tejeda, 2011).

Concept of Value

The concept of value in lean manufacturing refers to the operations required to transform raw materials and materials into a product that the customer is willing to pay for (Reyes, 2002).

Classification of Losses

Cuatrecasas et al. (2009) classified losses into three main categories based on their impact: availability losses, performance losses, and quality losses. Availability losses include the time interval between actual and planned operations. Performance losses refer to the variations between actual and ideal cycle times. Quality losses refer to the difference between the quantity of quality parts and the total quantity of parts.

Waste

According to Quesada et al. (2013), Toyota has identified seven categories of waste. These include excess production, waiting, unnecessary transportation, excess inventory, superfluous movements, and defective products. These wastes do not add value to the manufacturing process or the creation of a service.

Effects of Waste

Cuatrecasas et al. (2009) also note that waste has negative effects on companies. It reduces profits, increases the need for supervision, and makes companies inflexible.

Value Stream Mapping (VSM)

Value stream mapping (VSM) is a graphic representation of the value chain. It depicts the movement of materials and information from supplier to customer. It also records all productive operations on a sheet of paper and indicates where process waste occurs (Hernández & Vizán, 2013).

Preparing the VSM

To prepare the value stream map (VSM), García and Amador (2019) and Boronat (2014) suggest following the steps below:

1. Select a work team of 3 to 5 people who are familiar with the process.
2. Walk through the process several times to note down as many details as possible about how it works.
3. Choose the product family that has the greatest impact on the company's requirements.

Current State Map

According to García and Amador (2019), the initial state map represents the process as it is at the time of the study, in its current state. To create the current state map, the times of transformation of raw material into the product and process times that do not add value to the product, such as waiting times or delivery times, must be recorded.

Identifying the Value Stream

To identify the value stream, Tejeda (2011) recommends analyzing each step of the process, from design and engineering to launch. This helps to recognize activities that add value and those that do not, which are known as waste or *muda*. The main objective of lean manufacturing is to eliminate waste.

Single-Minute Exchange of Die (SMED)

SMED is a method used to enhance machine setup. It notes that changeover is made up of two operations: internal operations, which are performed when the equipment is idle, and external operations, which are performed while the machine is in operation. By studying the progression of activities and modifying some internal operations into external ones, the bottleneck caused by the accumulation of components resulting from the previous process is eliminated. This results in changeovers that take only a few minutes. The SMED system is versatile and can be applied to any industrial process and any machine (Sarango & Abad, 2009).

METHODOLOGY

This research follows an experimental design, as it was conducted during the production process to study the effect on productivity using a pretest and a posttest. According to Bernal (2010), in this type of research, *el investigador ejerce poco o ningún control sobre las variables extrañas, los sujetos participantes de la investigación se pueden asignar aleatoriamente a los grupos y algunas veces se tiene grupo de control* [the researcher has little or no control over extraneous variables. The research participants can be randomly assigned to groups, and sometimes there is a control group] (p. 146.).

There are a total of 18 workers in the pre-mixing manufacturing plant, who work in rotating groups of six for each of the three work shifts, all of whom were selected for this study. The sample size was determined deliberately using a non-probability method. This was done to conduct quasi-experimental work using the lean manufacturing methodology, specifically SVM and SMED.

The study included three workshops focusing on lean manufacturing, teamwork, and continuous improvement.

Before the workshops, a pretest analysis was carried out on the selected sample. Then the VSM and SMED tools were applied, followed by a posttest. The results of the posttest varied and a hypothesis was proposed to verify if there is a relationship between the decrease in plant downtime and the improvement methodology. Statistical tools were used to verify the hypothesis. Tests were conducted before and after applying the strategies to measure their effectiveness.

Work Teams

The work teams consisted of production engineers, production coordinators, and operational employees. Each team was assigned to a specific work shift and was responsible for implementing the lean manufacturing tools.

Training

Upon receiving training, the production manager provided training to the work teams on lean manufacturing, which included VSM and SMED.

RESULTS

The effectiveness of the lean manufacturing philosophy in reducing plant downtime was evaluated by comparing the results before and after implementing VSM and SMED in the pre-mixing manufacturing plant.

Hypothesis

H_0: The plant downtime obtained after implementing VSM and SMED of the lean manufacturing philosophy is not significantly higher than before the methodology was applied.

H_0: $u_1 = u_2$

H_1: The plant downtime obtained after implementing VSM and SMED of the lean manufacturing philosophy is significantly lower than before the methodology was applied.

H_1: $u_1 < u_2$

Table 2 shows the results of the excessive plant downtime problem before and after the lean manufacturing methodology was applied. It can be observed that the application of the VSM and SMED reduced plant downtime. The descriptive statistics of indicators "plant downtime (before)" and "plant downtime (after)" are shown in Table 3 and Table 4, respectively.

Normality tests were conducted using the SPSS tool to analyze the data of "plant downtime (before)" and "plant downtime (after)" after the application of the lean manufacturing methodology's VSM and SMED from Table 4.

Hypotheses

H_0: The analyzed data follows a normal distribution.

H_1: The analyzed data does not follow a normal distribution.

The assumptions for this test are as follows:

If

$p > 0.05$, H_0 is accepted;

$p < 0.05$, H_1 is accepted,

Table 2. *Results of the Plant Downtime Before and After Implementing VSM and SMED.*

Day	Downtime (Pretest) (min/t)	Downtime (Posttest) (min/t)	Difference (Before-After)
1	43	8	35
2	43	8	35
3	44	8	36
4	43	8	35
5	44	8	36
6	43	8	36
7	41	8	33
8	44	8	36
9	42	8	35
10	47	9	38
11	44	8	36
12	45	8	37
13	44	8	35
14	43	8	35
15	43	8	36
16	43	8	36
17	43	7	36
18	44	7	36

Source: Prepared by the author.

Normality Tests

For samples < 30, apply the Shapiro-Wilk test.

For samples > 30, apply the Kolmogorov-Smirnov test.

Based on the results of the Shapiro-Wilk test presented in Table 5, the data analyzed does not follow a normal distribution. This is because the significance of the "plant downtime (before)" test is less than 0.05, and the significance of the "plant downtime (after)" test is greater than 0.05. Therefore, a non-parametric test such as the Wilcoxon test should be used.

Wilcoxon Test

Hypotheses

H_0: The plant downtime obtained after implementing VSM and SMED of the lean manufacturing philosophy is not significantly higher than before the methodology was applied.

H_0: $u_1 = u_2$

Table 3. *Descriptive Statistics of Plant Downtime (Before)*

Statistics

Plant Downtime (Before).

N	Valid	18
	Missing	0
Mean		43.5734
Std. Error of Mean		.27648
Median		43.3989
Mode		41.08[a]
Std. Deviation		1.17302
Variance		1.376
Skewness		.867
Std. Error of Skewness		.536
Kurtosis		3.432
Std. Error of Kurtosis		1.038
Range		5.72
Minimum		41.08
Maximum		46.80
Sum		784.32
Percentiles	25	43.1217
	50	43.3989
	75	43.9742

a. Multiple modes exist. The smallest value is shown.

Source: Prepared by the author.

Table 4. *Descriptive Statistics of Plant Downtime (After)*

Statistics

Plant Downtime (After).

N	Valid	18
	Missing	0
Mean		7.8342
Std. Error of Mean		.08368
Median		7.7658
Mode		7.06[a]
Std. Deviation		.35500
Variance		.126
Skewness		.030
Std. Error of Skewness		.536
Kurtosis		.529
Std. Error of Kurtosis		1.038
Range		1.51
Minimum		7.06
Maximum		8.56
Sum		141.02
Percentiles	25	7.6247
	50	7.7658
	75	8.0843

a. Multiple modes exist. The smallest value is shown.

Source: Prepared by the author.

Table 5. *Normality Test Results for the Plant Downtime Indicator.*

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
Plant Downtime (Before)	.190	18	.084	.886	18	.033
Plant Downtime (After)	.130	18	.200*	.984	18	.983

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

Source: Prepared by the author.

H_1: The plant downtime obtained after implementing VSM and SMED of the lean manufacturing philosophy is significantly lower than before the methodology was applied.

H_1: $u_1 > u_2$

The assumptions for this test are as follows:

If

$p > 0.05$, H_0 is accepted;

$p < 0.05$, H_1 is accepted.

According to the data presented in Table 6, hypothesis H_1 can be accepted, as the Wilcoxon mean difference test performed before and after the implementation of the VSM and SMED has a significance level of 0.000, which is less than 0.05. Therefore, the plant downtime obtained after implementing VSM and SMED of the lean manufacturing philosophy is significantly lower than before the methodology was applied.

DISCUSSION

With a significance level of 0.000, or less than 0.05, the test shows that there is a significant difference between the plant downtime before and after the application of the lean manufacturing methodology's VSM and SMED.

Table 6. *Mean Differences of Plant Downtime (Before and After).*

Null hypothesis H_0: η = 0
Alternative hypothesis H_1: η > 0

Sample	N for Test	Wilcoxon Statistic	P-Value
Mean Diff. Plant Downtime	18	171.00	0.000

Source: Prepared by the author.

Minitab 15 was used for the one-tailed contrast.

Therefore, the hypothesis stating that the plant downtime obtained after the application of the VSM and SMED is significantly lower than the downtime obtained before the application of the methodology can be accepted. Therefore, this indicates that lean manufacturing principles are being implemented in the pre-mixing manufacturing plant, which is consistent with the theories and practices of this methodology.

By applying VSM and SMED, it was possible to detect the prolonged downtime caused by product changeover that was causing a bottleneck in the process. Product changeovers are necessary, but repetitive operations that can be optimized. The process was made up of internal and external operations that were performed when the plant was not operating. Activities were analyzed and some of the internal operations were changed into external ones, which were performed while the plant was in operation. This led to a reduction in the product changeover time, eliminated the bottleneck, and improved the process.

The lean manufacturing methodology and the application of VSM have demonstrated the importance of observing and monitoring the production process in plants. This approach has led to the successful implementation of the SMED technique, which is a continuous improvement tool that focuses on reducing changeover time in a production line. By observing the activities and movements involved in changeover, time was taken from unnecessary or inefficient activities, allowing for a more efficient production process. The information collected was analyzed to identify areas of improvement.

The principles of lean manufacturing, which focuses on eliminating waste and continuous improvement, are similar to those of the Total Quality Management Theory. Constant plant downtime is wasted time, which is also related to the approach of total quality management.

Similarly, the results obtained are in line with the Process Optimization Theory, as lean manufacturing also identifies and eliminates activities that do not add value to production processes, which is crucial for process optimization.

CONCLUSIONS

The implementation of the lean manufacturing methodology's value stream mapping (VSM) and single-minute exchange of die (SMED) of the lean manufacturing methodology resulted in a reduction in plant downtime. This improvement will contribute to better compliance with production plans, increased profitability, and enhanced customer satisfaction.

The findings of this research study will aid in developing strategies to acquire knowledge for further advancement of the production process.

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