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Using DMAIC Methodology and Lean Manufacturing Tools in the Brewing Industry in Northwest Mexico to Increase Delivery Times and Sales

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Abstract – An investigation was made in a brewery industry of the Ensenada city, Baja California, Mexico, located in the northwest of the Mexican Republic, to evaluate the percentage of punctuality in deliveries of different styles of craft beer, at various stages of the manufacturing lines. Currently, a low rate of 56.7% was presented, in the first six months of 2023, which represents a poor productive performance of the personnel and machinery in the manufacturing area and indicates that the established goals are not being met. This has caused delays both in internal areas of the evaluated company, as well as in delivery to the client, causing a decrease in sales and causing concern in the management, supervision and cost areas, due to the fact that an additional cost of $10,000 dollars was generated until March 2023, compared to the income projection if deliveries were timely. Based on this, the DMAIC (Define, Measure, Analyze, Improve, Control) methodology was applied using lean manufacturing improvement tools to improve on-time delivery performance and thus minimize additional costs and increase production efficiency. This occurred once this methodology was applied, presenting an 89% rate of on-time delivery, and thus increasing sales.

Keywords: DMAIC, lean manufacturing, production efficiency, brewing industry, costs.

1.INTRODUCTION

Mexico ranks fourth as a beer producer internationally, and first in export volume. This type of industry, over the years, has gained greater importance at the national level, considering that production in 2022 was 110,943 hectoliters, to reach a volume of 189,250 hectoliters in 2023, which represents an increase of 70.5% in just one year, according to data from the Asociación de Cerveceros de México (ACERMEX)1. From the

above, it follows that 2019 was a very positive year, maintaining the growth trend of previous years; however, in April 2020 and due to the health crisis caused by the level of contagion of the SarsCov2 virus, which causes Covid-19, a restriction was observed in the production levels of craft beer manufacturers in order to prevent further infections. All this led to a shortage in the craft beer market, which lasted for several weeks. Considering that 2023 was a year marked by the considerable increase in beer production volumes and the year 2020 turned out to be atypical, and what is happening in 2023, with poor production performance. The present scientific study aims to evaluate the punctuality of delivery at various stages of the manufacturing lines of the evaluated company, with tools from the DMAIC methodology and lean manufacturing, with which both the productive performance of the operating personnel and production line machinery were improved. With these tools, the possible causes presented for non-compliance with the delivery schedule established both internally and to the customer were analyzed. Applying the DMAIC2 methodology, the critical quality characteristics were defined and the causes of the delay in the delivery of orders were detected, through the application of a customer needs map; process mapping tools and Pareto3 diagram. In the development of the research, the critical quality characteristic (CTQ) was defined as on-time delivery expressed as a percentage. The contribution of the DMAIC and lean manufacturing methodology tools in this research was very relevant, due to the rapid and timely intervention to detect the causes of the delay in the delivery of orders. The results obtained in this first stage of the research, with the application of the Define and Measure phases of the DMAIC methodology, allowed to establish the bases for a second stage where a quick solution was given to each problematic situation, which affected the low productive performance of the personnel and machinery in the manufacturing area with the Analyze, Improve and Control phases.

1.1 DMAIC Methodology

This methodology is widely used in the improvement of industrial processes, to quickly and effectively detect the causes of problematic situations presented in manufacturing areas, having a strong connection with the Six Sigma methodology, following the bases of the phases of this methodology1. Each letter of the name of this methodology is a phase that is considered relevant in the improvement of production processes. Each phase is explained below 2:

a) **Define-Define:** It is denoted by quickly detecting the problematic situations to be evaluated in the production processes of an industrial company, where the variables to be analyzed are determined. In this phase, observations are made or numerical data is evaluated as a history of each stage of the industrial processes.

b) **Measure-Measure:** It is the phase where the editions of the variables proposed in the previous phase are made, using the appropriate methods and equipment. In this phase, the characteristics to be evaluated are determined, as well as the analysis methods and the way of collecting the data and the statistical tools to be used in the analysis.

c) **Analyze-Analyze:** This is where each problematic situation is assessed using the numerical data obtained at each stage of the industrial processes analyzed. In this phase, the analyses are developed with the tools defined in each type of analysis, with the objective of obtaining the optimal numerical data to determine what happens at each stage of the industrial processes, identifying the main causes and possible consequences.

d) **Improvement:** It is characterized by developing the pertinent improvements that help prevent problematic situations from occurring again. In this phase, structural or functional prototypes are developed (annual or automated systems that regulate the desired characteristics at each stage of the industrial processes. With this phase, failures are reduced or eliminated, and the operational efficiency of workers and machinery in manufacturing areas is increased, in order to achieve optimal control of the industrial processes.

e) **Control:** It is essential in the evaluation of the improvement processes by constantly observing their productive performance and thereby avoiding the recurrence of problematic situations. This phase is developed using statistical tools, one of which is the control chart, which identifies the levels or ranges of operation and expresses them in tables and graphs to be evaluated by expert personnel.

These five phases of this methodology are very relevant to avoid unnecessary expenses, cost reduction, delays in manufacturing and delivery times between stages of the manufacturing areas and to the customer, in addition to increasing the productivity and efficiency of industrial processes, as well as the quality of manufactured products. Another important factor is that with this methodology you can streamline procedures for the development of industrial processes3.

1.2 Lean Manufacturing

It is a type of analysis model used to develop the necessary evaluations in industrial processes, with the main objective of achieving the elimination of the greatest amount of waste, applying continuous improvement tools. It was started in the Toyota company in the 1960s, for quality control in automobile manufacturing. This type of management model evaluates activities that do not generate added value to both the process and the manufactured product, increasing the value of each industrial operation and discarding what is not needed. The most commonly used improvement tools in this model are 5S, total productive maintenance, just in time, Kaizen, Kanban, rapid model change, Poka Yoke and value stream mapping4. With this, it is possible to increase both productivity and profitability and competitiveness in industries, in addition to maintaining the profit margin and having better customer satisfaction. Lean manufacturing generates great commitment among employees, improving staff recruitment and retention to obtain greater economic benefits. This model considers eliminating the seven main types of waste (overproduction, long waits, excess transportation, excess operations in industrial process lines, excess inventory, unnecessary movements and defects.

1.3 Beer Industry

This type of industry represents one of the 14 most important industrial processes in our country, being as relevant as the manufacturing industry (electronics, aerospace, medical and automotive, essentially), in addition to the oil and pharmaceutical industries. In this type of industry, generic or normal beer and craft beer are manufactured. Craft beer produces a fermented beverage, which is made mainly with barley malt, hops, yeast and drinking water. It currently has 34 styles, derived from its own recipes, among which 10 of them are used in the regular production line, while the remaining recipes have been developed as experimental and/or in collaboration with sister breweries of the craft beer movement in Mexico. Figure 1 shows six main clients of the evaluated company, which have agreed to state as the reason when returning their order, that:

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1. The product is out of specification (less beer than requested)
2. Delay in the agreed date of delivery of the product

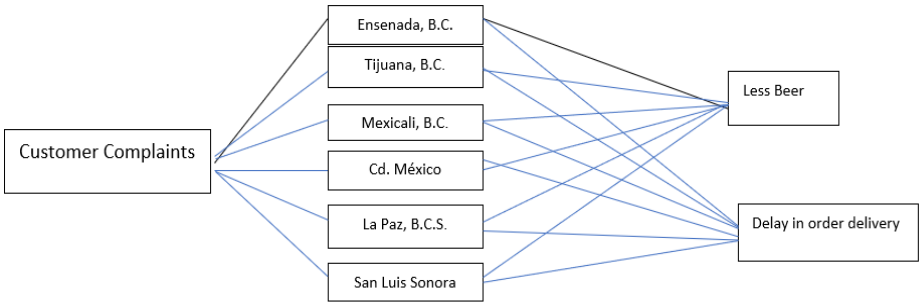

Fig -1: Customers in the industry evaluated and types of complaints

1.4 Description of the method

The DMAIC methodology, which stands for Define, Measure, Analyze, Improve and Control, is used to solve problems, focusing on improving processes5. This investigation was focused on the application of the five stages mentioned, linking it with lean manufacturing tools, which represents a quality management model for the search for improved productive performance of operating personnel and machinery in manufacturing areas, through making the right decisions4. The phases of the DMAIC methodology applied in this research are explained below:

a) **Define:** This phase focused on defining the problematic situation, establishing the metrics that were used6. In the present research, the efficiency of punctuality in the delivery of orders of the various styles of craft beer of the evaluated company was established as an indicator of productive performance, observing that punctuality in deliveries barely reaches 56.7% in the first three months of 2021. The established goal is to achieve 95% punctuality in the delivery of orders, so that this is reflected in an increase in income of $20,000 dollars per year. Considering the above, it is highlighted that the search for process improvement must meet the customer's requirements in terms of "delivery time, price and quality"7.

b) **Measure:** In this second phase, information was obtained from the activities carried out with measurements for the collection of numerical data, at each stage of the production line, to have the periods of lower productive performance8. In this phase, tools such as the customer needs map (CNM), needs detection, brainstorming and Pareto diagram9 were used.

c) **Analyze:** Once the variables to be measured were detected, analyses were carried out using lean manufacturing tools, with a qualitative evaluation of the 5'S, total productive maintenance and just in time, to determine the main causes of the delivery delays.

d) **Improve:** Certain activities were modified according to the process flow for the packaging of beer, with the aim of generating a faster and more efficient flow.

e) **Control:** After making the changes in the production process, evaluations were carried out with control charts to standardize each stage of the industrial process in the two production lines.

This analysis was considered because complaints were made by various clients due to delays in the delivery of the products, generating a loss of 10,000 dollars until June 2023.

2. METHODOLOGY

This is a descriptive field investigation, which used the DMAIC methodology, to define the problem and measure the process, and thereby detect the causes of late delivery of the product to the client and at each stage of the manufacturing area of the evaluated company. This analysis is expressed in the two phases mentioned below:

a) **Problem Definition Phase:** The variables that caused the delay in deliveries within the evaluated company and to the client were detected, taking as a primary reference the complaints presented by the clients during the first month of the year 2023, observing the aforementioned economic loss, the amount of which was obtained by integrating all the orders rejected and canceled by the various clients, due to the impossibility of making the delivery in the agreed time. The indicator of optimal productive performance was obtained from the following equation, with which the mentioned percentage was obtained.

$$\text{Efficiency} = \frac{\text{Total orders delivered on time}}{\text{Total Orders}} \quad \text{Equation 1}$$

b) **Process measurement Phase:** A brainstorming session was generated as the first part of this phase, with the participation of members from different levels of the organization, to detect the possible causes of the delay in the delivery of orders, and subsequently, a Pareto Diagram was created to identify the main causes of the delay in the delivery of orders.

c) **Analysis Phase:** Three types of analysis were developed with the lean manufacturing tools mentioned in the previous section, with the description of the characteristics causing the delays with different periods of time, considering that with these tools the most relevant information would be obtained for the control of industrial processes.

d) **Improvement Phase:** The operations that caused the delays were detected and the appropriate modifications were developed to improve the productive performance of the operating personnel and machinery in manufacturing areas.

e) **Control Phase:** In order to maintain the optimal productive performance of the operating personnel and machinery in manufacturing areas, control evaluations were carried out, obtaining the expected results and increasing times, productivity, quality and competitiveness.

3. RESULTS

The generation of delay periods in delivery between manufacturing stages of the brewing company and with the client, caused great concern in the management and supervisory staff, so the analysis was developed with the DMAIC methodology with only the definition and measurement phases, where the three remaining phases are considered in a following analysis stage. For this stage, evaluations were developed that are indicated in the following sections.

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3.1 Phases of the DMAIC Methodology

To define the main causes that caused the problematic situation of delay in delivery of the product in the manufacturing stages of the brewing company evaluated and to the client, quantitative and qualitative analyses were developed that are expressed below. The analyses of the five phases were developed, with the continuous improvement tools.

3.2 Data collection

Information was collected on customer orders for the year 2019, identifying the critical characteristics of on-time delivery, and the average productive performance of operational personnel and machinery in manufacturing areas linked to on-time deliveries was established in the order of 56.7%, as shown in Table 1.

Table -1: Efficiency of delivery time

Critical Characteristics of Quality (CCQ)	
City	Entregas a tiempo
Ensenada, Baja California	45%
Tijuana, Baja California	60%
Mexicali, Baja California	50%
Cd. de México	70%
La Paz, Baja California Sur	75%
San Luis, Sonora	40%
Average	56.7%

In the table above, it can be seen that the best performance in the on-time delivery service is in the city of La Paz, B.C.S. where it reaches 75%. Subsequently, a brainstorming session was developed, represented in Table 2, and was made this investigation to improve on-time deliveries.

Table -2: Brainstorming to improve on-time deliveries

No.	Ideas	No.	Ideas
1	Shortage of raw materials	5	Quality Problems
2	Equipment washing time	6	Lack of transportation
3	Getting the bottles	7	Communication errors
4	Production limitation	8	Lack of capital

3.3 Evaluation With Lean Manufacturing Tools

The development of evaluations with this type of tools is of great relevance, because with these, the main causes that originate the problematic situations that so concern management and supervisory personnel

can be quickly and easily detected. One of the evaluations was made in this investigation, evaluated the 5'S' analysis, which are presented in Table 3, to qualitatively determine if the stages of each industrial process were in their optimal organization, and thus be able to obtain the required information in a correct way, without generating incorrect data that would cause a deviation from the information necessary to be able to detect the main causes of the late delivery of the products within the evaluated company and to the client. The analysis was carried out from January to June 2021, where a comparison was made with the previous year, which even with Covid19, in this evaluated period this problematic situation did not arise. One of the aspects to be considered was that certain personnel of the company evaluated who worked in 2022, no longer worked in 2023 due to staff cuts or illness of them or their family members and they had to leave work. The company evaluated has 100 workers from the manufacturing area to the administrative and security areas.

Table -3: Qualitative analysis of use 5'S in manufacture areas of the brewing industry (January -June 2023)

Months	January	February	March	April	May	June
Factors						
Seiri-Eliminate	NA	NA	A	A	A	A
Seiton-Order	NA	A	A	A	A	A
Seito-Clean	NA	A	A	A	A	A
Seiketsu-Standarizate	NA	NA	NA	A	A	A
Shitsuke-Discipline	NA	NA	NA	A	A	A

Approved, NA. Not Approved

The table above was the development of an evaluation of observations made by the supervisory staff at each stage of the industrial processes, indicating that in the first two stages of the investigation, the 5'S were not 100% passable. The following evaluation was the total productive maintenance (TPM) analysis presented in table 4 in the same period as the analysis in table 1, considering the percentage levels of operational performance of the twelve machines used in the two production lines (six in each production line, which are machines (two input mixers, two beer fillers and two beer level inspection machines)). Once the total productive maintenance activity was developed, which consisted of preparing the machines on the production lines for operations with long periods, an analysis of the percentage of operability was developed, represented in table 4.

Table -4: Analysis of Total Productive Maintenance (TPM) in manufacturing areas of brewing industry (January -June 2023)

Months	January	February	March	April	May	June
Industrial Machines, % of Operation						
Mixer 1	56	67	70	75	81	84
Mixer 2	58	69	74	78	84	83
Filler 1	54	66	76	79	83	85
Filler 2	59	64	77	77	82	84

Inspection Action 1	56	67	74	79	80	85
Inspection Action 2	58	66	73	78	80	84

The table above illustrates the percentage levels of operability, observing that it increased as continuous improvement was applied, starting from levels greater than 50% to levels greater than 80%. This analysis was carried out to determine how much the operational performance of machines in manufacturing areas affected product delivery times. A just-in-time evaluation was subsequently was made, analyzing the proposed delivery times and measured times presented in the period of the first months of 2023, where the research represented in Table 5 was made.

Table -5: Analysis of Just at Time in the manufacturing areas of brewing industry (January-June 2023)

Months	January		February		March		April		May		June	
Average time of delivery, minutes	PT	MT	PT	MT	PT	MT	PT	MT	PT	MT	PT	MT
Step of delivery in inputs	15	23	15	21	15	19	15	17	15	16	15	15
Step of mixed	30	41	30	38	30	35	30	32	30	31	30	30
Step of filled	30	43	30	36	30	34	30	32	30	30	30	30
Step of inspection	15	26	15	22	15	20	15	17	15	17	15	15
Step of package	15	23	15	20	15	18	15	16	15	16	15	15

PT. Proposed Time, MT. Measured Time

The table above shows the proposed and measured time periods in the manufacturing stages presented in said table, observing that as the research progressed, the measured periods were equal to those proposed, eliminating late delivery times.

4. CONCLUSIONS

The main problem identified was the delay in the delivery of orders, where for the year 2022, a level of productive performance of the personnel and machinery in the manufacturing area was determined, performance in the average delivery time, in the order of 56.7%. Four main causes were detected, which are limitation in the production volume; shortage of raw material; limited quantity of bottles and washing time of the equipment greater than contemplated. Due to all the above, it was suggested to counteract the limitation in the production levels, as an immediate or short-term solution, for the acquisition of more pots and fermenters, through obtaining a preferential refill credit, which would minimally affect the financial stability of the company. For the shortage of raw material, requests and purchases were made in advance or, if possible, make purchases in larger volumes to achieve a reserve appropriate to the projected demand. To reduce the bottle supply problem, the same suggestion was made as before, that is, to purchase a larger number of bottles, more in line with the contracted sales volume. To solve the problem of equipment washing time, temporary staff could be hired, exclusively dedicated to this task. The secondary problem that was detected in the company evaluated is the volume of filling of beer bottles, so it is recommended to establish modifications in the quality control process and thus ensure volumes closer

to those established and accepted by customers at the time of establishing the purchase and sale contracts.

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