Volume 15, Issue 4, 152423 (1-26)

International Journal of Industrial Chemistry (IJIC)

https://dx.doi.org/10.57647/j.ijic.2024.1504.23

Improving production efficiency by implementing DMAIC phases on the Six Sigma method: a case study on the oil industry

Hamid Esmaili*, Reza Bornak, Afsaneh Shahrokhi, Hossein Jadidi

Department of Industrial Engineering, North Tehran Branch, Islamic Azad University, Tehran, Iran.

***Corresponding author:** h_esmaili@iau-tnb.ac.ir

Original Research

Received:
30 July 2024
Revised:
10 August 2024
Accepted:
15 August 2024
Published online:
30 November 2024

Abstract:

High-level competition in business requires improving the quality of the organization's product or service. Six Sigma with the DMAIC approach is a strategy that has been effective in improving product and service quality, and the concept of "Six Sigma" as an integrated strategy is still being developed. This article has tried to achieve qualitative and quantitative improvements in the oil production process of an FMCG company by using the Six Sigma method and implementing the DMAIC cycle. Therefore, we will first examine the basic concepts of Six Sigma, how to implement the DMAIC cycle, and the effective elements of production, and then identify the problems related to reducing stoppages, waste, and completing empty capacities in the oil industry.
Finally, we will consider increasing the production capacity to improve the overall effectiveness of the equipment. In the next step, with the help of mental storm sessions, the causes of the stops are investigated, and with the help of cause-and-effect diagrams, Pareto and MINITAB software, the main causes of the problem are identified and effective improvements are suggested.

Keywords: Six Sigma; DMAIC cycle; Pareto chart; Overall Equipment Effectiveness (OEE); SMART method; Process flow chart; Decision tree; FMEA failure analysis

1. Introduction

The expansion of economic activities is not a new phenomenon, but without a doubt, globalization is the most important and most obvious economic distinction between the world today and yesterday. Increasing competition at the economic and international level is one of the most important achievements of economic globalization. In order to deal with this storm of transformation and massive transformations and not to surrender to this wave of invasion, the competition between organizations has long shared one point, and that is to maintain approaches and focus all efforts towards achieving results. The results that lead to creating a competitive advantage and are effective and decisive in the performance indicators of the organization, including earning more money. The speed and quality of achieving performance indicators in a competitive world depends on the selection of detection methods and the use of organizations' capabilities and key competencies. Documenting methods and programs to clarify quality goals, customer orientation, attention to processes, transformation from a task-oriented organization to a process-oriented organization, continuous improvement approach, use of DMAIC improvement cycles, etc. are among the actions which has changed the situation of organizations and created significant qualitative leaps. Creating ISO standard quality management systems that have evolved day by day and played a very valuable role in organizing organizations [1].
In the 1960s to the 1980s, Total Quality Management (TQM) with zero-defect thinking had a significant impact on organizations. However, in the 1980s, in an environment where quality management with its classical concepts could not respond to rapid economic changes, this thinking underwent changes. With this change, the PDCA method was presented as a general framework for process improvement [2]. With the idea that there is always a superior thought above any thought, a type of re-engineering was done in TQM, which ultimately led to the creation of the Six Sigma

methodology [3].
In industries, the rate of production is a critical indicator because it determines how long the industry will last and how fast it will grow. This is why company owners are always looking for better ways to produce their goods to minimize waste and thus make the company more productive. One of the most important methods that can increase the productivity of a company is the Six Sigma method [4].
Today, by combining the two areas of lean production and Six Sigma, they have been able to create a significant improvement in the industry, because lean production is a way of thinking and principles that are used to improve the performance of a process through the elimination of waste and errors, and on speed, The flow and cost of a process is focused. On the other hand, Six Sigma is a method to increase process capability by analyzing processes by identifying problems and implementing improvements to solve problems, focusing on quality consistency and how to meet customer needs. A combination of Lean and Six Sigma will benefit organizations in determining the most appropriate method for identifying and solving problems, so the outcome of a process can provide customer satisfaction as long as profits are maximized. Therefore, in 2024, Ivana Tita Bella Vidyavati et al. examined this area in the food industry and introduced the DMAIC approach as a powerful tool [5].
The increasing competition in the industrial sector worldwide influences the business players to choose the right strategy. Providing quality products and services is one of the strategies to stay ahead of competitors [6]. Quality is important to business success and can be achieved if a process has good capabilities and meets specified requirements. Good performance in an industry is defined by examining a process that can produce products with low waste and minor defects. Efforts are required through structured steps to achieve consistent quality products. In the planning phase, a quality planning method is required. In the implementation phase, quality assurance is required. In the evaluation phase, quality control is essential [7]. Six Sigma is a proven approach for the world's largest companies to control processes and produce quality products.
Six Sigma is a profit maximization technique to identify waste and minimize it with the aim of achieving customer satisfaction, which was first successfully implemented by the Motorola mobile phone company in 1986. Since then, other companies have adopted it [8]. This technique follows a statistical approach and is achieved by minimizing variations and providing quality services or defect-free products. By reducing defects, less material is wasted and hence the optimization value of raw materials is fully utilized. Because Six Sigma seeks to improve the organization's capabilities and meet changing consumer demands, it uses data to provide better solutions, and statistically, achieving Six Sigma means that the products or outputs obtained have almost no defects. These are the results that every organization would like to achieve [9]. Six Sigma is a systematic and structured method, commonly known as DMAIC (Define, Measure, Analyze, Improve, Control), which is effective in identifying, measuring, analyzing, improving and controlling the process [10]. Six Sigma has been used as an effective management strategy in some of the world's largest companies to improve company performance [7, 11, 12].
Research has shown that the goal of most projects in the implementation of Six Sigma was to reduce costs, which can be implemented with the help of the DMAIC cycle (Table 1), so in order to implement Six Sigma as accurately as possible, it is necessary to pay attention to the effective factors in its implementation, so that with the help of it, the competitive power can be increased [13].
Six Sigma is a data-driven process improvement methodology used to achieve stable and predictable process results, reducing process defects [14]. [15] Defined it as a business strategy that seeks to identify and eliminate the causes of errors or defects or failures in business processes by focusing on outputs that are critical to customers. Six Sigma has been widely used in manufacturing and service industries for more than a decade to reduce defects, changes, eliminate errors to achieve product excellence, exceed customer expectations, and gain company performance [6, 11, 12, 16–19]. The Six Sigma method provides significant evidence of success in reducing waste and defective products in processes whose inputs are operators, raw materials, methods, machinery, and the environment. While in the service sector, the Six Sigma program can reduce human and system errors as well as non-value-added activities [20–22].
The most basic thought in the implementation of Six Sigma is to increase the capability of the process. In the manufacturing industry, increasing process capability can be more focused on controlling variation and defective products [11, 19].
Quality is an important requirement for business success in manufacturing and service industries. Also, productivity is a business mindset that is the main factor in increasing company profits [6, 23]. Quality and productivity can be created when the processes have good capabilities and can create processes and products that meet the requirements for customer satisfaction [24].
Six Sigma is a method that emphasizes process execution based on customer focus, prevention, commitment and management support [25, 26]. Six Sigma with DMAIC approach often uses quality tools known as seven tools, but the flexibility of Six Sigma can be enhanced with other tools such as TQM, ISO 9000, Lean Management and TOC (Theory of Constraints), etc. [27, 28].
The Six Sigma method begins with the recognition of the critical quality elements of a process in order to make suggestions for improvements related to the defects created [29]. Six Sigma has measurable improvement steps that lead to reduced costs and increased customer satisfaction to maintain a company's sustainability as an overall indicator [6, 30].
The main goal of Six Sigma is continuous improvement through a project. But the Six Sigma program is not easy and comes with obstacles. The three major obstacles that can often be encountered in the implementation of Six Sigma methods are [31]:
1. Lack of senior management commitment.
2. Advance costs for the project

Table 1. DMAIC cycle - D(Define) M(Measure) A(Analyse) I(Improve) C(Control).

Phase	Activity	Quality tools used	Result
Define	Project identification, project owner- Determining customer needs- Defining the problem, goals and- resources of the project- Definition of beneficiaries- Drawing a process map	Project Charter - Stakeholder Analysis - Process Outline - Voice of the Customer - Dependency Chart	Identifying the importance of the project - supporters, consultants and leaders - the type of process and the level of efficiency of the process
Measure	Determining the input and output of the project - performing the operational definition of the variables - establishing performance standards and developing a sampling and data collection plan	Data collection programs and forms - control charts, abundance, Pareto-prioritization matrix - process capability	Identifying process problems, identifying data patterns and current process capability
Analyse	Process modelling - Establishing causal relationships using data - Analysing the process map to determine the root causes of problems	Diagrams of dependence, cause and effect, control, flow and abundance, parto and rain of ideas	Identifying potential causes, capitalizing on the causes and how the data changes
Improve	Development of solutions - assessment of risk and success of solutions - validation of solutions - implementation of solutions and determination of their effectiveness	Design of experiments - Hypothesis testing - Stakeholder analysis - Brainstorming sessions - Consensus	Identification of solutions - criteria for selection and scoring of implementation solutions
Control	Determining the required controls and measurements - implementing the controls - showing the benefits of the implementation - ending the project and transferring the information about its results	Statistical control of the process - control charts - executive program outside the control limits and changes in the design in order to eliminate defects	How to standardize new methods - how to monitor processes and how to improve processes

3. Fear of change
But in fact, there will be no obstacle for not implementing the Six Sigma method in case of the commitment and responsibility of human resources (HR). The commitment of senior management is an essential factor for the success of Six Sigma, which can be implemented by implementing a suitable strategy that focuses on the customer and the team, and integrate improvement programs in a suitable and standard resource that focuses on training and teamwork [25]. In addition, managers should encourage employees by having a reward program and acknowledge the achievements of the human resources involved [32]. So that the support and commitment of senior management is one of the determining factors for the successful implementation of Six Sigma, which can lead to the removal of two other obstacles (cost and the culture of fear of change). Six Sigma tools are often used in a simple performance improvement approach called DMAIC, which is used when the goal of a project is to improve an existing product, process, or service [33]. The basic principle of the DMAIC approach is a structured algorithm with the following steps [34]:
1. Definition phase: The first step in the process of identifying or defining problems is determining the problems and goals that must be achieved [34]. This step is important and should not be skipped easily, because identifying the wrong problem will affect the analysis and the results obtained [11, 35, 36].
2. Measurement Phase: The second phase focuses on the project criteria and the tools used to measure those criteria. How can the situation be improved? How can the identified causes be quantified? In general, the measurement of critical quality factors is very important for tracking performance measurement [34].
3. Analysis Phase: The third stage is the analysis of the process so that the influencing variables can be discovered. Or in other words, the stage of identifying the current situation and identifying the opportunity for improvement [34]. In order to analyze and identify factors and causes of problems in order to determine effective measures that can improve the process.
4. Improvement Phase: This stage is a process that includes checking how the changes made in element X affect element Y. In this phase, you will identify how to improve the implementation of the process [34].
5. Control Phase: It is a stage for monitoring and standardizing the solution to ensure that the causes of the problems are controlled and also to get management support [25, 26, 34].
Based on the research conducted in the field of Six Sigma implementation in manufacturing industries, 72% of the articles consistently implemented the complete steps of DMAIC, especially in the case research type. Because in the case study, DMAIC phases are needed to maintain the stability of changes and defective products and will not be repeated in the future. Unlike descriptive research, which is usually the goal of scientific development, its implementation is simply done by comparing several different industries to obtain new knowledge and does not require correction or control steps. Therefore, in this article, we will examine

the improvement of production quality by implementing DMAIC phases on the Six Sigma method, a case study on the oil industry.

2. Overview of the Six Sigma methodology

Six Sigma focuses on improving process capability through structured stages known as DMAIC. Various research studies have demonstrated that Six Sigma (DMAIC) can address various issues experienced in manufacturing and service industries, including reducing product defects, lowering production costs, reducing error rates, minimizing customer complaints, increasing productivity, extending equipment lifespan, enhancing customer satisfaction, improving performance, and boosting business profits [31].
As depicted in Figure 1, different approaches exist for utilizing each of these methodologies within Six Sigma [4].
The Six Sigma methodology does not require a deep understanding of statistics. As mentioned earlier, it uses a statistical metric to describe the performance or quality of a product or service. Six Sigma is typically represented as "6σ," where "σ" is a Greek letter denoting sigma, which represents standard deviation. In statistics, standard deviation indicates how far data points are from the mean. A low standard deviation implies that data values are close to the mean, while a higher standard deviation indicates that data values are spread out. This characteristic reflects the dispersion among data points [4].
Another important statistical tool to enhance understanding of Six Sigma is the normal distribution curve, which describes the distribution of a set of data. The bell-shaped curve is cantered around the mean, meaning the mean is always at the centre. Approximately 68.2% of data points fall within one standard deviation from the mean, about 95.4% of the data set falls within two standard deviations, and roughly 99.7% falls within three standard deviations [37]. The percentage distribution of data points on the bell-shaped curve is illustrated in Figure 2.
The use of statistical tools in the implementation of DMAIC phases in Six Sigma is essential, but there is no strict rule regarding the specific tools to be used in each phase. Generally, the selection of tools for each phase depends on the type of project and the specific needs.
Important tools in Six Sigma include [31]:
1. Define Phase: Voice of the Customer (VOC), Voice of the Business (VOB), brainstorming, historical data, data collection, SIPOC diagrams, process maps, and flowcharts. These tools help identify all current issues to determine Critical to Quality (CTQ) parameters that need improvement.
2. Measure Phase: Capability analysis (sigma level), Pareto charts, Measurement System Analysis (MSA), control charts, ANOVA, Voice of the Process (VOP). These tools reflect the performance of measurable factors within the organization before improvement.
3. Analyse Phase: Cause and effect diagrams (CED), Pareto charts, Value-Added (VA) and Non-Value-Added (NVA) analysis, regression and correlation analysis, Root Cause Analysis (RCA), 5 W analysis, Failure Modes and Effects Analysis (FMEA). These tools can identify the root cause of the problem during the Define Phase and plan improvements by eliminating factors that hinder productivity.
4. Improve Phase: Design of Experiments (In the field of DOE, the RSM method is one of the most widely used. The response surface method, which includes a set of mathematical and statistical techniques, was used to determine the effect of these experimental values on the response and to find the optimal process conditions and the most effective variables on the response [38].), simulation, ANOVA, P-charts, Structural Equation Modelling (SEM), risk matrix, FMEA, 5 W 1 H, Box plots. These tools are corrective actions that can resolve the problem.
5. Control Phase: Standardization, documentation, work instructions (WI), control plans, control charts, Statistical Process Control (SPC), comparative data. The goal of these tools is to control processes for better consistency and product defect levels.

3. The role of Six Sigma in manufacturing

The primary goal of the Six Sigma approach is to achieve customer satisfaction by producing products with fewer defects. This is crucial in the manufacturing process be-

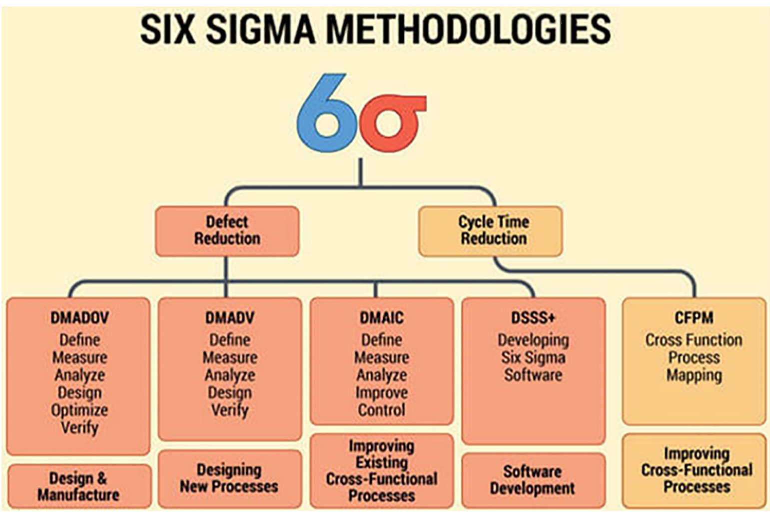


Figure 1. Six Sigma methods.

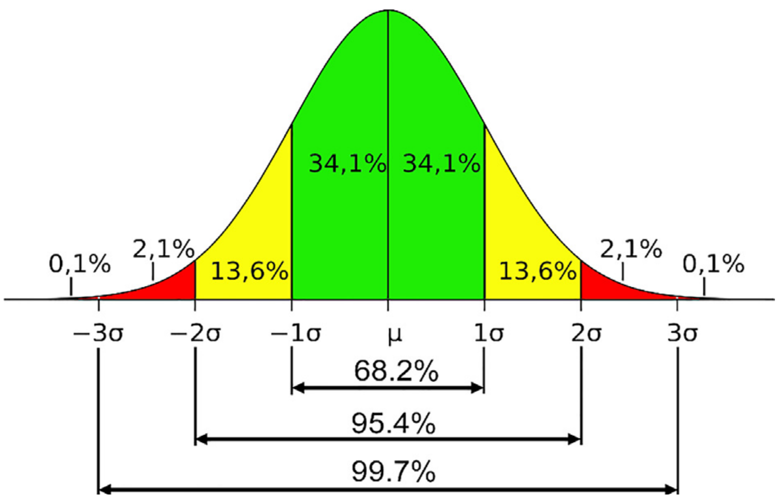


Figure 2. Percentage distribution of data.

cause products that do not meet customer requirements are rejected and returned for re-production, and only those without defects can be sold. A study has shown that when customers experience negative results from defective products or poor services, this experience doesn't just affect them personally but influences other customers and a larger community, leading to more customers boycotting the product or service [37]. Therefore, the emergence of a method called Lean Six Sigma drives production towards lean manufacturing. Lean manufacturing is a process improvement method that aims to provide better, faster, and lower-cost products and services by eliminating waste in production systems [39]. Defined it as follows:

"A method for determining value, organizing value-creating actions in sequence, conducting these activities without interruption whenever someone requests them, and achieving more with less human effort, equipment, time, and space, while providing exactly what the customer wants."

The Lean approach focuses on streamlining the flow of a process by searching for and eliminating non-value-added activities. It believes that by removing non-value-added activities, tasks can be performed more quickly and will have a significant financial impact. In contrast, the Six Sigma approach focuses on quality and defect reduction. It emphasizes identifying problems and defects and correcting them. In summary, Lean Six Sigma is all about speed and efficiency, ensuring that resources are working on the right activities. Lean ensures that resources are working on the right activities, while Six Sigma ensures that activities are done right the first time [40].

4. Implementation of the Six Sigma methodology with the deming cycle

Before discussing the phases of Six Sigma, it's necessary to examine the formula for calculating OEE (Overall Equipment Effectiveness) and the symbols used in this context. A summary of information is provided in Tables 1 and 2. symbols, the formula for calculating OEE is as follows:

$$\text{OEE} = \text{A} \times \text{P} \times \text{Q} \tag{1}$$

Additionally, the time required for setup and initialization is referred to as "Loading Time," which can be obtained from the following equation:

$$\text{Loading time} = \text{Total time} - \text{Planned STOPPAG} \tag{2}$$

Furthermore, the availability index includes parameters related to downtime: BD, CO, St, Ma, Ut, and Lg, which can

Table 2. Table of symbols

Symbol	Explanation
A	Availability
P	Productivity
Q	Quality
OEE	Overall equipment effectiveness
PR	Productivity Rate
PM	Packaging Material
PM	Preventive Maintenance
PS	Planning Stoppage
UPS	Unplanned Stoppage
CLIT	cleaning, lubrication, inspection, tightening
BD	Break down
MS	Minor Stoppage
Ma	Material Availability
MQ	Material Quality
MI	Material Inventory
Aj	Adjustment
Co	Change Over
Li	Cleaning
LO	Lack of Operator
OM	Operator Mistake
Rp	Replacement
SP	Speed loss
St	Startup
Ut	Utility
Hd	Shutdown

be obtained from the following equation:

$$\text{Availability}:\left(\frac{\text{Loading time–Availability time}}{\text{Loading time}}\right)\times 100 \quad (3)$$

The performance index includes parameters related to downtime: Ms, Aj, Rp, MQ, SP, Mi, Li, Io, OM, which can be obtained from the following equation:

$$\text{Performance}:\left(\frac{\text{Performance time–Availability time}}{\text{Loading time}}\right)\times 100 \quad (4)$$

Additionally, the production rate can be obtained from the following equation:

$$\text{PR\%} = \frac{\text{Actual production(MT)}}{\text{Capacity Production}} \quad (5)$$

Planned downtime includes parameters such as St, Li, HD, Co. Unplanned downtime includes parameters such as expected values from BD, MS, Ma, MQ, Mi, Aj, LO, OM, Rp, SP, Ut, and HD

4.1 Definition phase

4.1.1 Project selection reasons

In this phase, the main goal of an FMCG company for implementing Six Sigma is defined as follows: "To increase the overall efficiency of equipment (OEE), which is a measure of the machine's potential that exposes opportunities for improvement. OEE is implemented by manufacturers to identify, monitor, and reduce production losses. Thus, it has become a global KPI for manufacturers and the best method for lean production." Based on this goal, an issue analysis table is provided in Table 3. It is worth mentioning that the issues mentioned have been obtained through the SMART method, and their details are provided in the following Table 4.

4.1.2 Project stakeholders

Stakeholders in a project are individuals or entities with an interest in a company and can influence or be influenced by its business activities. The primary stakeholders in a company include investors, employees, customers, and suppliers. As per Table 4, the stakeholders' table is provided in Table 5.

4.1.3 SIPOC process map

The SIPOC diagram (Suppliers, Inputs, Process, Outputs, and Customers) is a visual tool for documenting the end-to-end business process before its execution In Six Sigma, SIPOC is often used during the "Define" phase of the DMAIC methodology (Define, Measure, Analyse, Improve, and Control). An example of a SIPOC map is provided in the Chart 1.

4.1.4 CTQ decision tree

In general, a decision tree is simply a list of deficiencies (inefficiencies) that may exist in the factory production process. In this improvement project, we are looking for options that will have the most significant impact on the company's success (improving OEE) and customer satisfaction. Therefore, by drawing a CTQ (Critical to Quality) tree for various options, we are seeking critical points in the process after conducting the investigations in brainstorming sessions and consulting with technical experts, as shown in Chart 2.

Table 3. Examining the problems of AN FMCG Company.

Business Case					
Problem	**Potential improvements**	**Potential impact**	**Rate**	**Financial / non-financial**	**Annual**
3% Improvement in OEE shortening unit	Optimization PM time	Reducing the cost of emergency stoppage and increasing the life of the devices	A	Financial	
	Reducing or optimize Change Over time with tools such as -(SMED)	Reducing device failure	B	Financial	
	Reducing MS stoppage	Increasing the life of machines and increase production capacity	B	Financial/ Non-financial	
	Reducing unplanned downtime stoppage	Reducing operator inspection costs	B	Financial	
	Increasing AM skills to operators	Reducing device failure	B	Financial/ Non-financial	
	Improving project analysis skills for SV	Improvement in the process of doing work, process optimization	B	Financial/ Non-financial	
	Process optimization by ECRS tool	Increasing the productivity and work efficiency of people and processes	B	Financial/ Non-financial	
	Reducing CIP time	Increasing production time	A	Financial	
	Reducing waste	Reducing production costs	A	Financial	

Table 4. SMART method information.

G	O	A	L	S	
1-making a team according to Belbin test 2-Holding regularly meetings with 6 sigma members 3-Implamantion of TPM 4-Identifing all of losses and unplanned stops 5-Definition of improvement projects (DMAIC, SMED, ECRS, ..) 6-Recording losses information correctly and daily 7-Comparing the data with the organization's goals, and then define the project, action plan, and training needed 8-Following the main program and training matrix with 6 sigma team members according master plan 9-praticipation and involvement all of 6 Sigma members in the designated programs	Following up every phase basis DMAIC methodology	Participation of all members of the organization in promoting organizational knowledge and implementing organizational projects in order to achieve minimize loss optimal OEE	Following up OEE losses basis DMAIC methodology	Short- Term	Identifying all of losses with 6 SIGMA team
				Long -Term	at least 3% reduction in total losses

4.1.5 CTQs table

The CTQs (Critical to Quality) table helps you translate general customer needs into specific, actionable, and measurable performance requirements. CTQs were originally developed as part of the Six Sigma methodology. The information obtained in this regard is presented in the Table 6 provided.

After conducting the initial project overview, we now move into the Measurement phase.

4.2 Measurement phase

It's worth mentioning that in this phase, decision-making sessions were conducted in two stages to examine the indicators. In the first stage, the decision-making process focused on improving the planned stoppage time as a PM activity, and in the second stage, it focused on reducing the unplanned stoppage time. The results of these decisions are presented below.

4.3 Fishbone diagram for identifying equipment downtime

The Fishbone diagram, as depicted in Chart 3 and Chart 4 were used during brainstorming sessions to identify the causes of equipment downtime.

4.3.1 Failure modes and effects analysis (FMEA) analysis

Based on the insights obtained from brainstorming sessions for identifying planned and unplanned stoppages, opinions regarding the causes of failures and proposed solutions are documented in Table 7 and Table 8, which pertain to the analysis of failure modes.

4.3.2 Pareto charts and failure causes

Pareto charts obtained from the failure causes based on Table 7 and Table 8 are presented in Figure **??** and Figure **??**. Based on Chart 5 and Chart 6, the causes of insufficient and incomplete information database, as well as the methods used to address recurring issues, are identified. These causes include the ineffectiveness of repair time, the ineffectiveness of maintenance program execution, the absence of a prerequisite checklist before starting maintenance activities for the planned stoppage (PM activity). Additionally, the causes related to the inappropriate quality of consumable tools (belt, bag clamp), increased power outages during peak consumption months (equipment breakdowns), increased fatigue-related failures, and inadequate skills of equipment contractors (pumps, etc.) for unplanned stoppage considerations are also identified.

4.3.3 Quick solutions

The proposed solutions in this regard are provided based on the failure causes in Table 9 and Table 10.

It should be noted that the average OEE before the project and during the first 6 months of the year was 75%, with significant fluctuations.

4.3.4 Analysis phase

In this analysis phase, statistical analysis is performed in three stages, and the details of each stage are provided in the Table 11.

4.3.5 Overall Equipment Effectiveness (OEE) performance area

Here, we want to investigate whether changing the formula of the Puff Pastry Margarine product has resulted in a significant difference in the OEE averages and determine its impact on the CTQ before and after this change has occurred. The Table of recorded information and assumptions is provided in Table 12.

The results of the two-tailed independent sample t-test in Figure 3 indicate that the null hypothesis is rejected. This means that with the formula change, OEE does indeed change.

4.3.6 Area of training effectiveness in AJ, RP, and PM

In this section, we aim to investigate whether the number of training hours per month has an impact on the stoppages related to AJ and RP. The data related to time is recorded in the Table 13 provided.

At first, we conducted a correlation test to examine the impact of training duration on the AJ parameter. The assumptions were considered, and the results obtained are presented in Chart 7.

Considering the obtained P-VALUE < 0.5 in this method, the null hypothesis is not rejected, indicating that the two variables are not significantly correlated according to this approach.

Subsequently, we proceeded to investigate the correlation test to assess the impact of training duration on the RP

parameter. Assumptions were considered, and the results obtained are as presented in Chat 8.
Considering the obtained P-VALUE < 0.5 in this method, the null hypothesis is not rejected, indicating that the two variables are not significantly correlated according to this approach.
Finally, we have examined that the time required for replacing the necessities in all three shifts will not differ significantly from each other. Therefore, information from the three shifts has been recorded in Table 14.
In this section, we have employed an analysis of variance (ANOVA) to test the equality of means across multiple populations. Assumptions were considered, and the results obtained are presented in Figure 4.
Considering the obtained P-VALUE < 0.5 in this method, the null hypothesis is rejected, indicating that there is a difference in the time required for replacing essentials across all three shifts. Additionally, for further examination, the confidence interval plot for the three shifts is presented in Chart 9.
Finally, the relationship between the three parameters, AJ, RP, and PM, is examined in the chart presented in Chart 10. The chart indicates that with an increase in training duration, the level of adjustments made by operators decreases.
For further examination, regression analysis of the duration of planned stoppages was performed with parameters HD, AJ, and CO in two stages, as shown in Figure 5 and Figure 6. The results indicate that in both stages, the regression obtained is statistically significant. In the first stage, all parameters except AJ have an influence in the regression model, and in the second stage, with the change in the coefficient of AJ, the significance of this parameter has also been established.
Additionally, the parameter impact matrices in two stages are presented in Chart 11 and Chart 12.
Additionally, a regression test for unplanned stoppages with parameters BD, MS, and MQ was conducted in two stages. The results obtained are shown in Figure 7 and Figure 8. The results indicate that in the first-stage regression analysis, the BD parameter does not have an impact on stoppage time, and with the regression model based on second-stage values, it is evident that the MQ parameter is not statistically significant and does not affect the model.
Furthermore, the parameter impact matrix for both stages is presented in Chart 13 and Chart 14.

4.4 Improvement phase

In this phase, considering the factors influencing the reduction of planned and unplanned stoppages and consequently increasing OEE, the cost of implementation, positive outcomes during execution in the improved process, and the adverse effects on other processes during execution, improvement solutions were identified and prioritized. Weighted parameter information is provided in Table 15.
Based on Table 15, the effects of improvements resulting from the actions can be observed in the figure. The results indicate that operator training has been highly effective in this regard.

4.5 Control phase

The control phase can be considered as the next step in sustaining and stabilizing improvements. It involves formalizing progress through modifications to rewards, policies, procedures, material resource planning (MRP), budgets, operational training, and other management systems.
Documenting the results and summarizing key findings, determining future projects, and using quality tools for control purposes are elements of the control phase. This includes implementing executive plans to control items outside of standard limits, controlling changes in design to eliminate defects, and more.
The Six Sigma methodology's approach in the control phase extends the positive project outcomes and manages these changes for integration into the overall system. This was achieved in this project through the following steps:

4.5.1 Development of process control plan

Given the positive results obtained in the Improvement Phase, it is necessary to specify how the process will be controlled in the areas that have undergone changes. In other words, it is essential to identify the changes resulting from the project and how these changes will be controlled to ensure their sustainability.
Before taking any action in the Control Phase, a process control plan must be developed to specify how the process will be controlled for the areas that have undergone changes. In this context, changes resulting from the project should be clearly identified, and the method for controlling these changes to ensure they continue should be defined.
To execute the development of the Process Control Plan, data obtained from unplanned stoppages and the OEE index were placed under control using control charts. As observed in the charts in Chart 15, there is an increase in the OEE rate in the second half of the year, and there is a decrease in the duration of unplanned stoppages in the second half of the year as well.
To control the two mentioned indicators in this project, I-MR control charts were used. Based on Chart 16 and Chart 17 in the Unplanned Stoppages chart, in December, data fell outside of control due to incomplete information, and in November, it was due to unplanned stoppages caused by oil shortages. As a result, these data points were considered outliers. Additionally, from month 6 onwards, there was a decrease in the average duration of unplanned stoppages.
Furthermore, based on Chart 18, from month 6 onwards, there has been an increase in the range of the average OEE. In month 11, due to issues in the treatment plant, OEE decreased.

4.5.2 Standardization of solutions

To institutionalize the solutions identified during the improvement phase, it is imperative to standardize these solutions, each according to its nature. Standardization involves defining a set of activities and responsibilities. To facilitate this process, the industrial company has prepared a table outlining these activities and responsibilities, and the details are presented in Table 17.

5. Conclusion

The Six Sigma methodology has been widely adopted across various industries, spanning from manufacturing to services. Its primary goal is centred on reducing variability in the production system, aiming to minimize deviations from the process mean. The Six Sigma methodology, based on the DMAIC process (Define, Measure, Analyse, Implement, Control), facilitates the identification of all factors contributing to system defects, understanding their root causes, and subsequently, their resolution.

Furthermore, Six Sigma can be described as a philosophy, as it strives to minimize errors, a statistical measurement, as it aids in precise measurement of products, services, and processes, and as a measurement tool, as it establishes a measurement system. Ultimately, it functions as a business strategy, as it enhances quality and reduces costs.

The effective and straightforward techniques introduced within the Six Sigma methodology, such as the SIPOC (Supplier, Input, Process, Output, Customer) process map, defect checklists, and various process capability metrics, help identify strengths and weaknesses within processes and pave the way for improving their status. Supportive tools, often referred to as Six Sigma tools, including cause-and-effect diagrams, Pareto charts, Failure Mode and Effects Analysis (FMEA), and Voice of the Customer (VOC) analysis, significantly contribute to addressing issues and challenges effectively, providing a clear picture of the company's performance for further investigation.

The objective of this article was to investigate the quality improvement in the oil industry by implementing the DMAIC phases using the Six Sigma methodology. The industrial company successfully achieved this objective by enhancing equipment efficiency through reducing unplanned downtime via operator training, ultimately resulting in profitability.

Table 5. Stakeholder analysis.

Stakeholder/ Stakeholder Group	Stakeholder name	Impact Level-	Strongly Against	Modernity Against	Neutral	Modernity Supportive	Strongly Supportive	Action(s) to Address This Stakeholder Group	Contact
Plant Executive Director	**Mr.Shokoohi**	Decision Authority				R	U	Invite senior managers of the organization to participate in the symposium	
Production manager	**Mr.Bornak**	Decision Authority					R		
Production SV	**Ms.Shahrokhi, Mr.Sotoodeh , Mr.Noori, Mr.Parsapour**	Will Be Affected				R	U	Invite senior managers of the organization to participate in the symposium	
Planning Manager	**Mr. Bagherpiry**	Impacts Outcome			R	U		Invite senior managers of the organization to participate in the symposium	
Planning SV	**Mr.Bagheri , Mr.Safarzadeh**	Impacts Outcome			R	U		1. Holding briefings and symposiums for experts 2. Holding training courses	
Technical manager	**Mr.Hashemipour/ Mr.Karimi**	Impacts Outcome		R		U		1. Holding briefings and symposiums for experts 2. Holding training courses	
electrical and mechanical technician	**Mr.Samanipour, Mr.Samarghandi, Mr.Heidari, Mr.Ghorbani**	Decision Authority		R		U		1. Holding briefings and symposiums for experts 2. Holding training courses	
Quality Assurance Manager / FSMS	**Mr.Amiri**	Impacts Outcome			R	U		Invite senior managers of the organization to participate in the symposium	
Quality Assurance SV / FSMS	**Mr.Mohammadi, Mr.Rezaee**	Impacts Outcome			R	U		1. Holding briefings and symposiums for experts 2. Holding training courses	
Shop floor	**all of shortening operators**	Impacts Outcome			R			1. Holding briefings and symposiums for experts 2. Holding training courses	
Finance		Impacts Outcome			R	R		Invite senior managers of the organization to participate in the symposium	

Current R; Desire U

Table 6. Table of CTQs.

NEEDS	CTQs	MEASURE	DEFECT DEFINITION	Kano
Reduce Planing Stoppage Time	Synchronization time between PM and CIP time	Reducing Stoppage from 64 hours to 60 hours	Increasing time by more than 60 hours	Performance Needs
Reduce MS and BS Time	Improve the status of planing stopage time as PM activity	Reduceing MS time	Increasing MS time from 26,000 minutes per month	Performance Needs

Table 7. Failure Mode Effects Analysis (FMEA) - CTQ1.

Process/Step	Potential Failure Mode	Potential Failure Effect	Severity (SEV)	Potential Causes	occurrences (OCC)	Current Process Control	Detection Ability (DET)	Risk Priority Number (RPN)
What is the step?	In what ways can the step go wrong?	What is the impact on the customer if the failure mode is not prevented or corrected?	***Move the mouse here to know the rating criteria***	What causes the step to go wrong? (i.e., How could the failure mode occur?)	***Move the mouse here to know the rating criteria***	What are the existing controls that either prevent the failure mode from occurring or detect it should it occur?	***Move the mouse here to know the rating criteria***	*RPN = [SEV] x [OCC] x [DET]*
Improving overall OEE (at least 3%) with focusing on major losses	Increasing the duration of planned stops (PM, Change over, CIP)	Increasing the duration of repairs as a non-added value activity and reducing production time	10	Lack of continuous activity in improving AM activities	7	AM Audit - AM Reporting	1	7
				Low technical skills of production operators	7	Training Matrix - Scoring	1	7
				Not having a program to reduce the duration of changing the line	5	ECRS Plan -SMED	5	25
				Ineffective repair time	8	-	10	80
				Not paying attention to reducing CIP time (not adjusting the amount of soda and acid)	3	-	10	30
				Failure to pay attention to the correct layout of the production plan to reduce the changeover, CIP times	5	Change Over SOP	5	25
				Not having the right tools to make repairs faster	3	-	8	24
				Failure to pay attention to the timely replacement of parts and equipment	6	PM Planning	7	42
				Failure to update IF DOWN DO for optimal use of stop times	4	AM Reporting	1	4
				Not having an effective plan to	5	Overhaul Checklist Annually	3	15

Continue of Table 7.

Process/Step	Potential Failure Mode	Potential Failure Effect	Severity (SEV)	Potential Causes	occurrences (OCC)	Current Process Control	Detection Ability (DET)	Risk Priority Number (RPN)
				overhaul the devices annually				
				Not having a program to prioritize between devices to perform repairs	4	-	8	32
				Lack of efficient people during repairs	5	Shortening ECAS	7	35
				Not having a prerequisite checklist before starting the repair program	8	-	8	64
				Failure to coordinate the schedule of repairs according to the request and needs of the technical team, which leads to rework.	6	Forecast Plan	5	30
				The effectiveness of the implementation of the repair program	8	-	10	80
				The lack of a complete database of the list of failures and methods used to solve repeated problems	10	-	10	100

SIPOC Diagram

S	SUPPLIERS who is providing input to a process	I	INPUT resource provided by supplier for incorporation to process	P	PROCESS steps taken to convert input to output	O	OUTPUT resource resulting from process	C	CUSTOMER receiver of newly created output
PROCESS TITLE:			Shortening						
SUPPLIERS		INPUT		PROCESS		OUTPUT		CUSTOMER	
01-Jan-00	Refinery		Refined Oil	01-Jan-00	Refined Oil		Table Margarine		Shirin Asal
02-Jan-00	Asan Tabriz		Carton	02-Jan-00	Tank Farm		Cheese Margarine		Minoo
03-Jan-00	Rezvani Pour		Nylon	03-Jan-00	Crystallization		PPM (2kg Plate)		Anata
04-Jan-00	Asan Tabriz		Layer page	04-Jan-00	Filling		PPM (5kg Plate)		Farkhondeh
05-Jan-00	imaji		Inkjet Printer	05-Jan-00	Control Weight				Sobhaneh Talaee
06-Jan-00	Henkel		Hot Melt	06-Jan-00	Jet Printer				Kaleh
07-Jan-00	Rezvani Pour		Roll bag	07-Jan-00	Palletizing				
08-Jan-00	Rezvani Pour		HDPE slab film	08-Jan-00	Storage in Refrigeretor				
09-Jan-00	Savashi		The essence of domino jet printer	09-Jan-00					
10-Jan-00	Savashi		Savashi Sanitary Detergent	10-Jan-00					
11-Jan-00	imaji		Wash 800 towels	11-Jan-00					

Chart 1: Process SIPOC diagram.

Table 8. Failure Mode Effects Analysis (FMEA) – CTQ2.

Process/Step	**Potential Failure Mode**	**Potential Failure Effect**	**Severity (SEV)**	**Potential Causes**	**occurrence (OCC)**	**Current Process Control**	**Detection Ability (DET)**	**Risk Priority Number (RPN)**
What is the step?	In what ways can the step go wrong?	What is the impact on the customer if the failure mode is not prevented or corrected?	***Move the mouse here to know the rating criteria***	What causes the step to go wrong? (i.e., How could the failure mode occur?)	***Move the mouse here to know the rating criteria***	What are the existing controls that either prevent the failure mode from occurring or detect it should it occur?	***Move the mouse here to know the rating criteria***	*RPN = [SEV] x [OCC] x [DET]*
Improving overall OEE (at least 3%) with focusing on major losses	Increasing the duration of unplanned stops (MS.BD, ...)	Reduce production time	10	Lack of sufficient knowledge of operators	10	Training Matrix - Scoring	1	100
				Inadequate skills of equipment contractors (pumps,...)	9	-	10	900
				Low quality of essentials (carton,...)	10	Quality Assurance Checklist	2	200
				Inadequate quality of consumer tools (belts, bag clamps)	10	-	10	1000
				Increase in power outages during peak consumption months (device breakdowns)	10	-	10	1000
				Failure to fully implement PM activities due to not having a proper plan	8	PM Planning	5	400
				Ineffectiveness of PM repairs	8	-	10	800
		Reducing the productivity of manpower	6	Increasing the amount of breakdowns caused by labor fatigue	10	-	10	1000
		Increasing the cost of repairs and reducing the useful life of devices	10	Equipment set point not calibrated	8	Calibration Checklist	2	160
				Not having Back Up spare parts in the unit to replace and reduce downtime	8	-	6	480
				Not paying attention to the repair receipt or replacing the parts before stopping the machine	8	PM Planning	4	320
				Failure to provide spare parts on time by the purchasing unit	8	-	5	400

Table 9. Quick solution table for CTQ1.

#	Causes of rapid improvement	Make Improvements	Owner	Executer	When	Deadline
1	Inadequate quality of consumer tools (belts, bag clamps)	Provision of spare parts according to the Spec defined by the technical team or the device manufacturer	Maintenance Unit	Purchasing Unit	11/23/2021	2/1/2022
2	Increase in power outages during peak consumption months (device breakdowns)	Correspondence with the electricity organization to announce the blackout schedule in order to switch on the company's electricity	Utility Unit	Utility Unit	11/24/2021	2/1/2022
3	Increasing the amount of breakdowns caused by labor fatigue	Employing labor according to the workload defined for them	Production Unit	HR Unit	11/25/2021	2/1/2022
4	Inadequate skills of equipment contractors (pumps,...)	Defining the minimum skills and resources required to enter into a contract with qualified contractors	Maintenance Unit	Purchasing Unit	11/26/2021	2/1/2022

Table 10. Quick solution table for CTQ2.

#	Causes of rapid improvement	Make Improvements	Owner	Executer	When	Deadline
1	Inadequate quality of consumer tools (belts, bag clamps)	Inadequate skills of equipment contractors (pumps,...)	Maintenance Unit	Purchasing Unit	11/23/2021	2/1/2022
2	Increase in power outages during peak consumption months (device breakdowns)	Correspondence with the electricity organization to announce the blackout schedule in order to switch on the company's electricity	Utility Unit	Utility Unit	11/24/2021	2/1/2022
3	Increasing the amount of breakdowns caused by labor fatigue	Employing labor according to the workload defined for them	Production Unit	HR Unit	11/25/2021	2/1/2022
4	Inadequate skills of equipment contractors (pumps,...)	Defining the minimum skills and resources required to enter into a contract with qualified contractors	Maintenance Unit	Purchasing Unit	11/26/2021	2/1/2022

Table 11. Assumption test table in the analysis phase.

Possible X (1 or 2 words)	Null Hypothesis	Alternative Hypothesis (Your theory)	Hypothesis Test (See Hypothesis Tree on Next Tab)	P-Value or R-Squared	Results (Accept or Reject Null)
Formula	By changing the Puff Pastry formula, there will be no change in the OEE percentage.	By changing the Puff Pastry formula, the OEE percentage of the product changes.	Two-Sample T	P = .508	Accept Null
Training Time	Changing the number of training hours per month will not have any effect on the amount of stops related to AJ and RP	The amount of training hours will have an impact on the number of stops related to the replacement of parts and settings.	Correlation	P. AJ =0.032 P.Rp =0.94	Reject Null Accept Null
Time Period	The time of changing the essentials in all three shifts does not differ much	The time of changing the essentials is different in all three shifts.	ANOVA	P = .888	Accept Null

Table 12. Table of recorded data and tested hypotheses for OEE.

Date	Average of OEE	Formula
001225	55%	1
001226	84%	1
001227	91%	1
010131	78%	2
010201	80%	2
010211	64%	2
010214	46%	2
010216	61%	2
010217	50%	2
010218	90%	2
010219	86%	2
010303	71%	2
010304	78%	2
010305	88%	2

Table 13. Timeline information table to investigate the effectiveness of training in AJ and RP.

Row Labels	Sum of No - Training	Sum of Person *hour	OEE%	AJ (min)	RP (min)
2021	446	13380			
9	60	1800	0.802582214	1540	2645
10	244	7320	0.800071308	1825	3329
11	142	4260	0.805567182	1233	3123
2022	220	6960			
1	14	420	0.813989136	2876	3521
2	76	2280	0.770603443	3138	1720
3	38	1140	0.767166607	2610	1629
4	8	240	0.758242533	2898	1882
5	49	1830	0.762411244	3050	1472

Table 14. Information table of 3 shift work requirements.

The time of changing the essentials in every three shifts - minutes.			
Month	**Parsapur**	**setudeh**	**nori**
1	1403	1131	870
2	711	465	519
3	358	569	702
4	580	553	749
5	577	490	405

Table 15. Weighting table of factors affecting improvement.

Criterion / Criterion	Implementation cost	Running time	The number of personnel involved in the implementation	Negative consequences during execution in the process being improved	Negative consequences after implementation in the improving process	Destructive impact on other processes during execution	Destructive impact on other post-execution processes	How long the effects last after healing	Positive consequences during execution in the improved process	Positive consequences after implementation in the improved process	Positive effects during execution in other processes	Positive effects after implementation in other processes
Implementation cost	1.00	8.00	10.00	0.13	0.13	0.13	0.13	0.13	6.00	6.00	8.00	7.00
Running time	0.13	1.00	5.00	0.10	0.10	0.10	0.10	0.10	0.13	0.11	0.11	0.11

Continue of Table 15.

The number of personnel involved in implementation	0.10	0.20	1.00	0.10	0.10	0.10	0.10	0.10	0.13	0.11	0.11	0.11
Negative consequences during execution in the process being improved	8.00	10.0	10.00	1.00	5.00	0.17	0.17	4.00	0.25	0.25	0.25	0.25
Negative consequences after implementation in the improving process	8.00	10.0	10.00	0.20	1.00	0.17	0.17	5.00	0.25	0.25	0.25	0.25
Destructive impact on other processes during execution	8.00	10.0	10.00	6.00	6.00	1.00	8.00	0.17	0.25	0.25	0.25	0.25
Destructive impact on other post-execution processes	8.00	10.0	10.00	6.00	6.00	0.13	1.00	0.17	0.25	0.25	0.25	0.25
How long the effects last after healing	8.00	10.0	10.00	0.25	0.20	6.00	6.00	1.00	0.25	0.25	0.25	0.25
Positive consequences during execution in timproved process	0.17	6.00	6.00	4.00	4.00	4.00	4.00	4.00	1.00	6.00	6.00	6.00
Positive consequences after implementation in the improved process	0.17	9.00	9.00	4.00	4.00	4.00	4.00	4.00	0.17	1.00	0.17	0.50
Positive effects during execution in other processes	0.13	6.00	6.00	4.00	4.00	4.00	4.00	4.00	0.17	6.00	1.00	2.00
Positive effects after implementation in other processes	0.14	9.00	9.00	4.00	4.00	4.00	4.00	4.00	0.17	2.00	0.50	1.00

Table 16. Overall results of the improvement made.

	Weekly - (Personel * Hours) duration of execution	Positive consequences during execution in the improved process	Positive effects after implementation in other processes	Final weight
Weight criteria	2 %	12 %	10 %	
Holding internal trainings	6 %	81 %	4 %	0.10
Rotating the workforce	6 %	13 %	30 %	0.04
Preparation of device manuals and manuals	87 %	7 %	66 %	0.08

Table 17. Information table for standardization of solutions.

Row	Kind of CTQ	Main CTQ	Xi′ CTQ	Action Plan	Variable type
1	CTQ1	Ineffective repair time	The presence of specialized and trained people during repairs	1- Assessment of maintenance training needs for operators 2- Preparation of educational program 3- Involving all production operators in carrying out repairs	Standardization of variable qualitative variable
2	CTQ1	Failure to pay attention to the correct layout of the production plan to reduce the changeover, CIP times	Compliance with the production schedule according to the order of oil color (from low to high color)	Submit production instructions based on oil paint to the planning unit	Standardization
3	CTQ1	Failure to pay attention to the timely replacement of parts and equipment	Preparing a master list of the last replacement time of parts and specifying the next replacement time		Standardization
4	CTQ1	Not having an effective program to overhaul the devices annually	Preparation of the annual master list of equipment prioritization		Standardization
5	CTQ1	Not having a program to prioritize between devices to perform repairs	Validation of all problems registered in the system	Approval of people in the CMMS system	Poke-Yoke
6	CTQ2	Lack of sufficient knowledge of operators	Preparation of instructions and reference standards for the reference of the operator		Standardization
7	CTQ2	Inadequate skills of equipment contractors (pumps,...)	Preparation of instructions and reference standards for the reference of the operator		Standardization
8	CTQ2	Not paying attention to the repair receipt or replacing the parts before stopping the machine	Doing CLIT		Standardization
9	CTQ2	Failure to provide spare parts on time by the purchasing unit	Preparation of the master list of spare parts inventory and sending in time intervals to specific people in a systematic way		Standardization

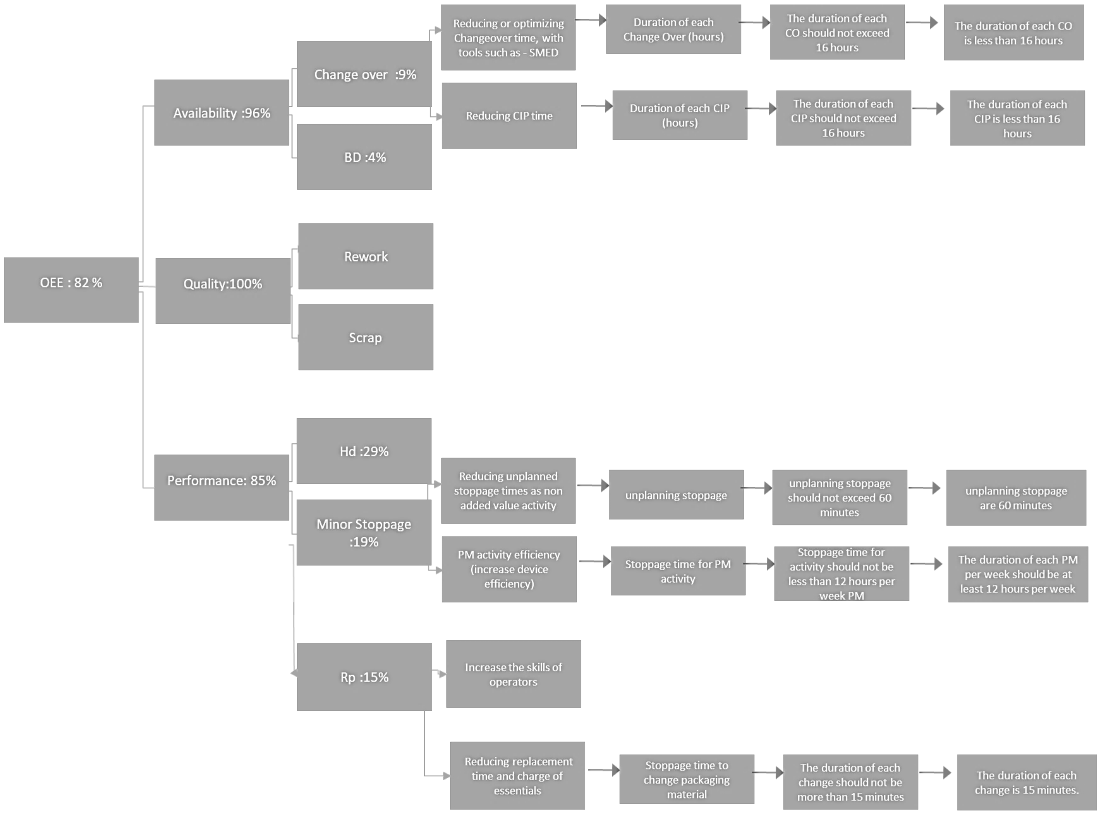


Chart 2: CTQ decision tree.

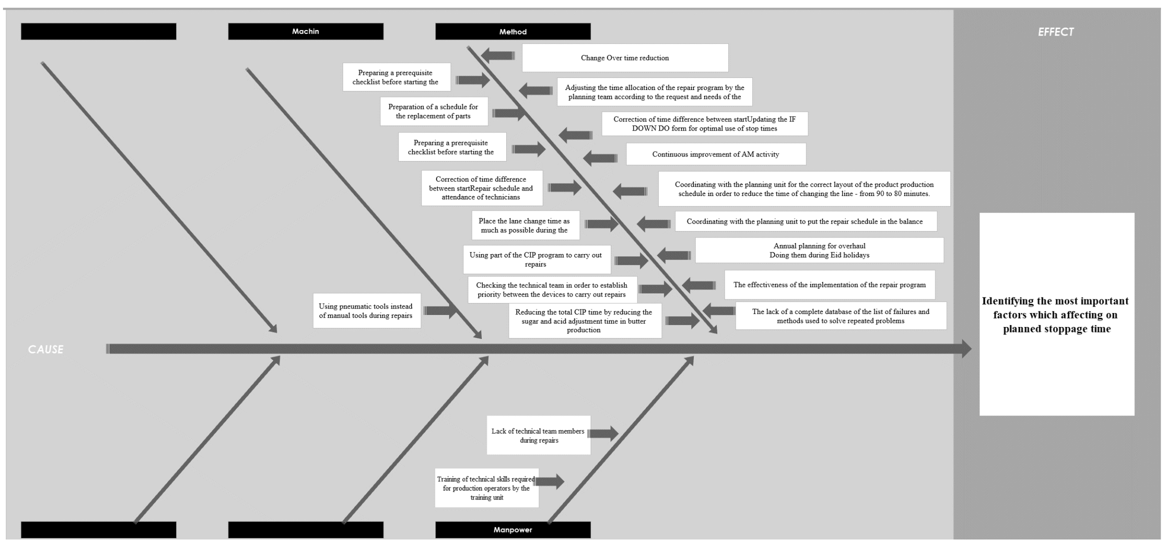


Chart 3: Cause and effect diagram of brainstorming sessions.

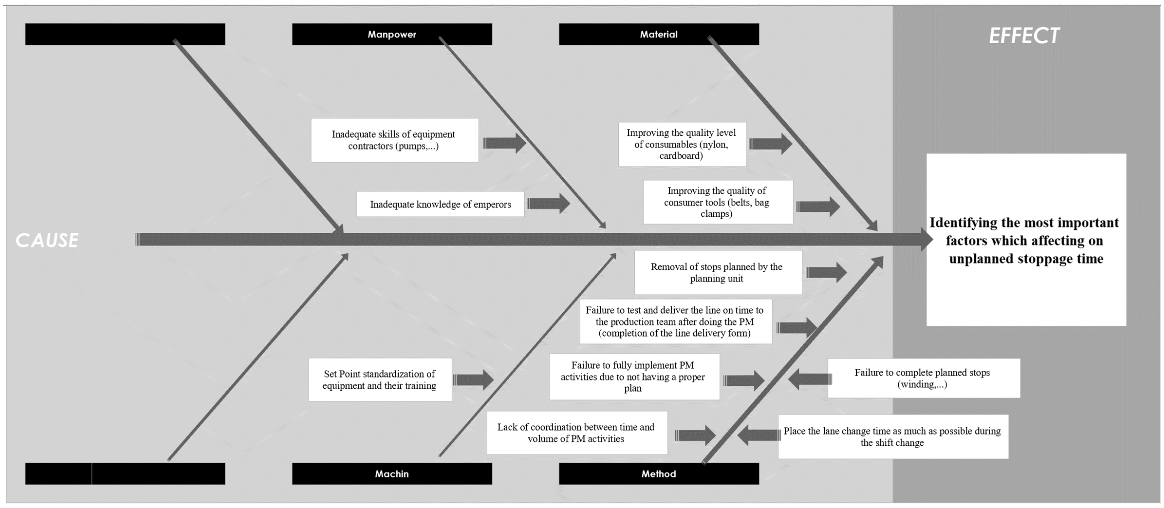


Chart 4: Cause and effect diagram of brainstorming sessions.

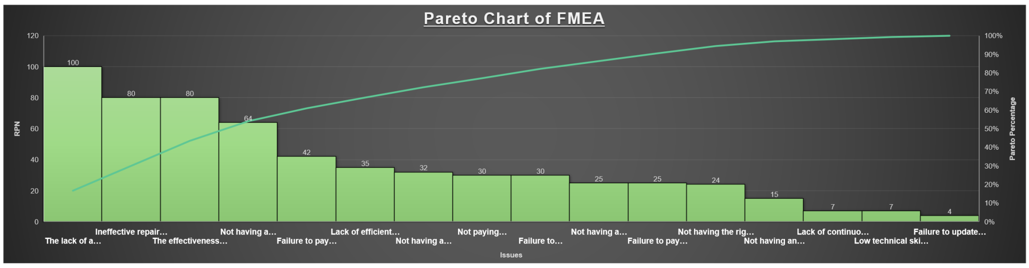


Chart 5: Pareto chart FMEA - CTQ 1.

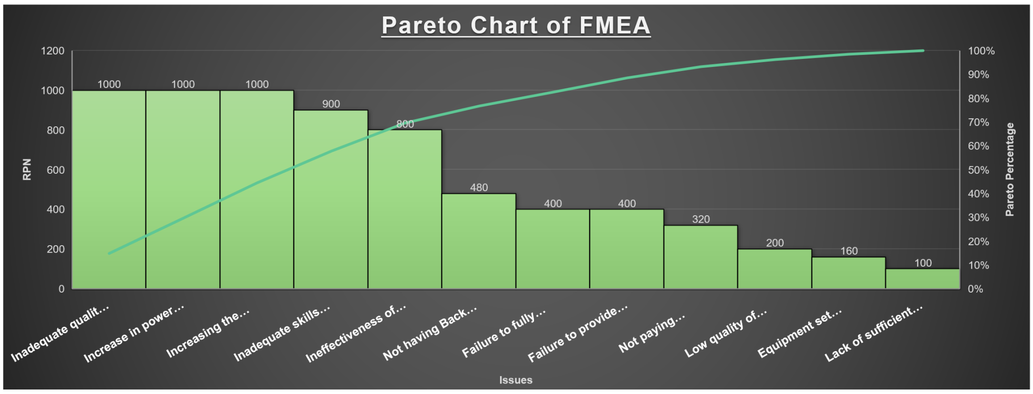


Chart 6: Pareto chart FMEA - CTQ 2.

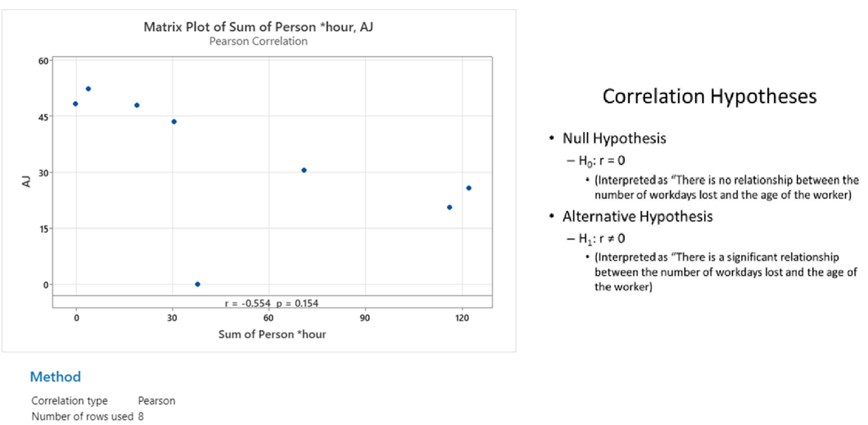


Chart 7: Test of Equality of Means for Two Independent Communities: Person*hour, AJ.

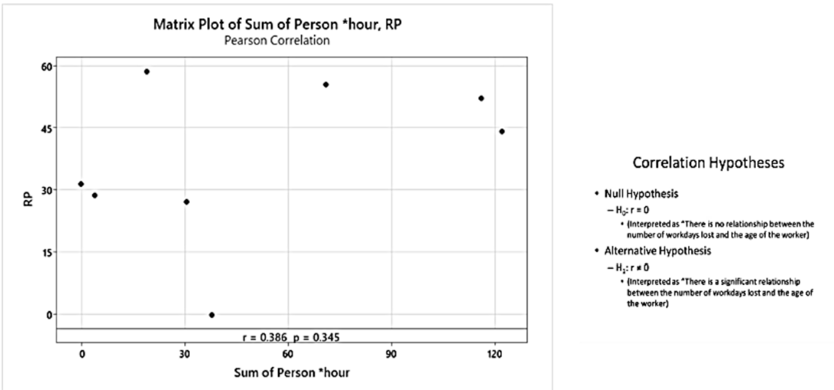


Chart 8: Equality test of means of two independent communities: Person*hour, RP.

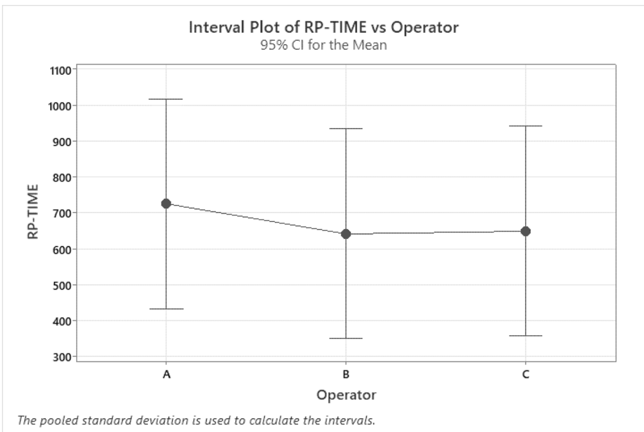


Chart 9: Confidence interval for mean RP-TIME VS OPERATORS.

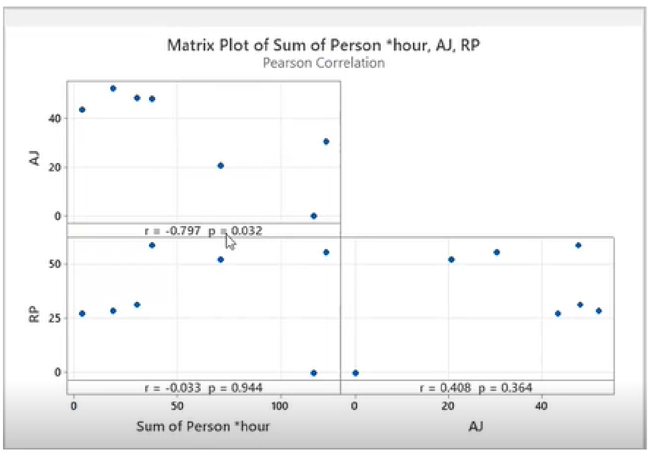
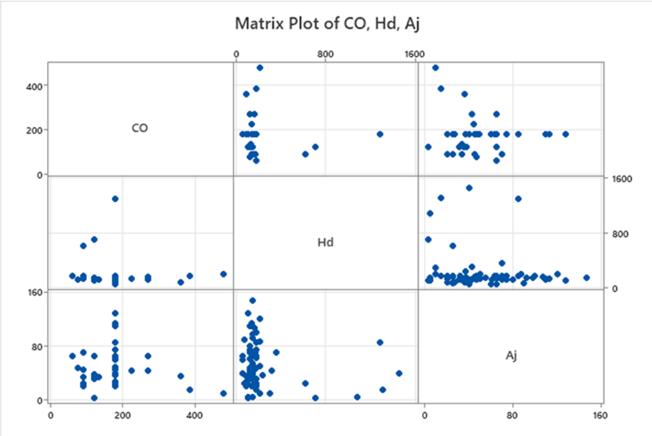


Chart 10: Correlation matrix between three parameters AJ, RP and PM.

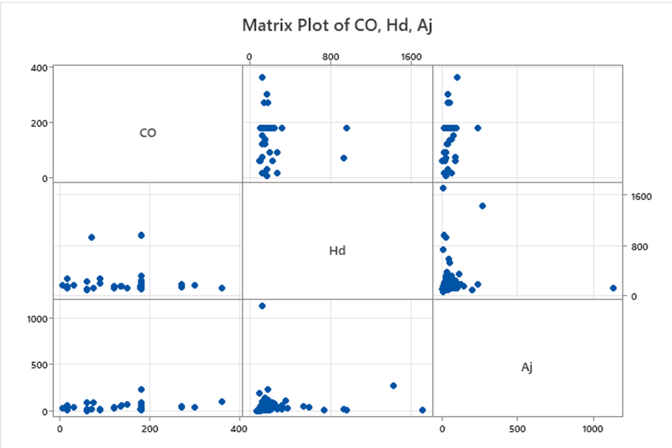


Response is Unplaned Stoppage-1

36 cases used, 45 cases contain missing values

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	CO	Hd	Aj
1	6.4	3.6	0.0	0.7	161.50		X	
1	1.2	0.0	0.0	2.5	165.93			X
2	7.7	2.1	0.0	2.3	162.81		X	X
2	7.4	1.8	0.0	2.3	163.01	X	X	
3	8.4	0.0	0.0	4.0	164.66	X	X	X

Chart 11: The influence matrix of the parameters of planned stops in the first stage.

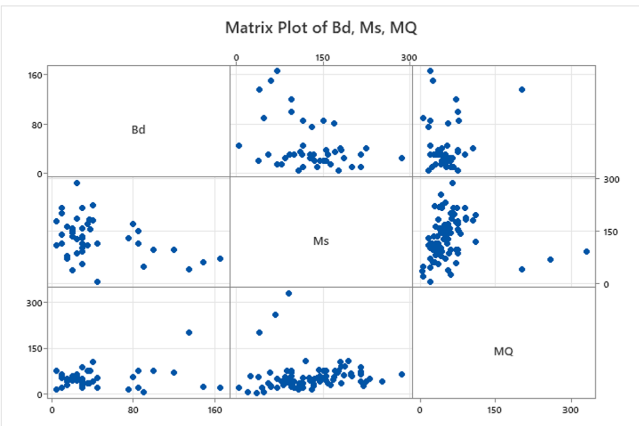


Response is Unplaned Stoppage 1

73 cases used, 43 cases contain missing values

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	Ms	MQ	Bd
1	37.6	36.7	33.1	3.9	143.14			X
1	0.7	0.0	0.0	47.1	180.60		X	
2	41.0	39.3	31.7	2.0	140.23	X		X
2	37.8	36.0	31.8	5.7	143.94		X	X
3	41.0	38.4	30.8	4.0	141.22	X	X	X

Chart 12: The impact matrix of the parameters of the scheduled stops in the second stage.

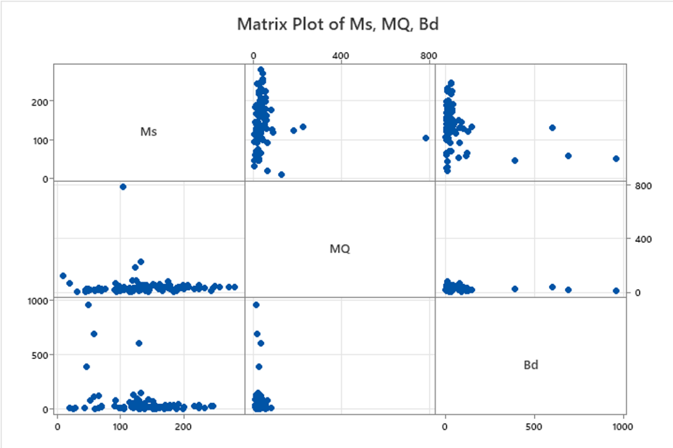


Response is Unplaned Stoppage-1

44 cases used, 37 cases contain missing values

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	Bd	Ms	MQ
1	25.5	23.7	16.3	14.3	119.38		X	
1	23.4	21.5	9.4	15.9	121.08			X
2	42.5	39.7	34.5	3.9	106.10		X	X
2	32.0	28.6	15.3	11.6	115.47	X	X	
3	45.2	41.0	32.4	4.0	104.95	X	X	X

Chart 13: Matrix of effects of unplanned stops parameters in the first stage.



Response is Unplaned Stoppage 1

73 cases used, 43 cases contain missing values

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	Ms	MQ	Bd
1	37.6	36.7	33.1	3.9	143.14			X
1	0.7	0.0	0.0	47.1	180.60		X	
2	41.0	39.3	31.7	2.0	140.23	X		X
2	37.8	36.0	31.8	5.7	143.94		X	X
3	41.0	38.4	30.8	4.0	141.22	X	X	X

Chart 14: Matrix of effects of unplanned stops parameters in the second stage.

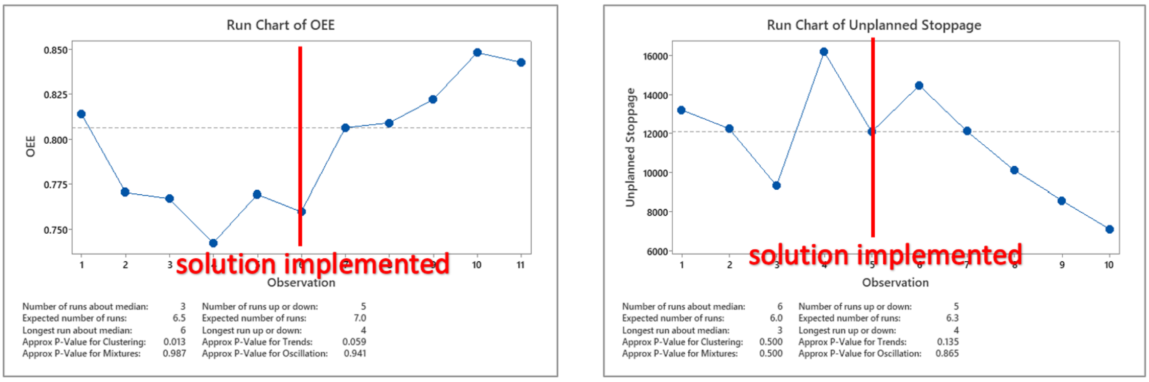


Chart 15: OEE trend chart and unplanned stops.

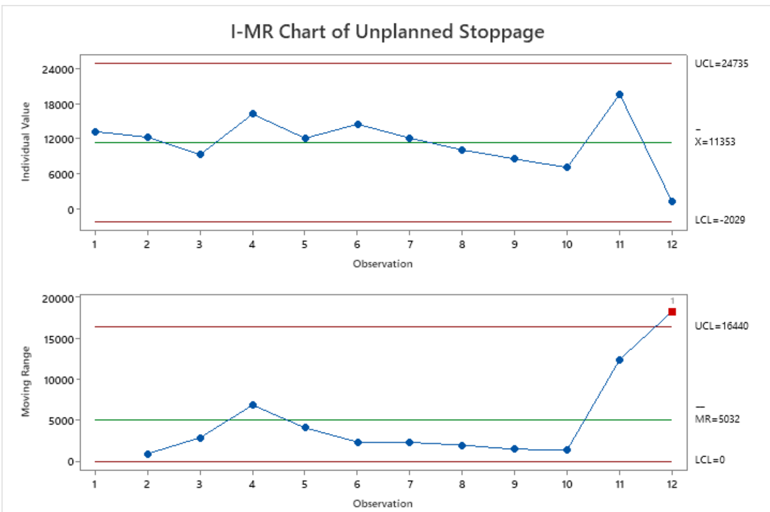


Chart 16: I-MR diagram of unplanned stops for the first 12 months.

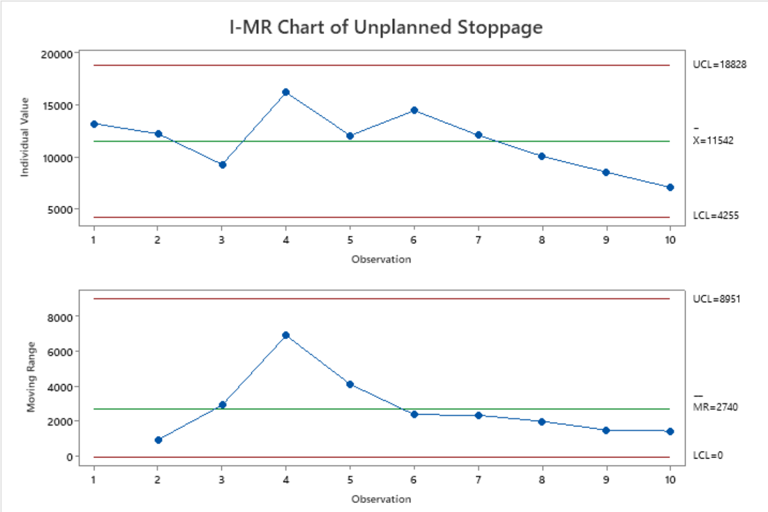


Chart 17: I-MR diagram of unplanned stops for the second 12 months.

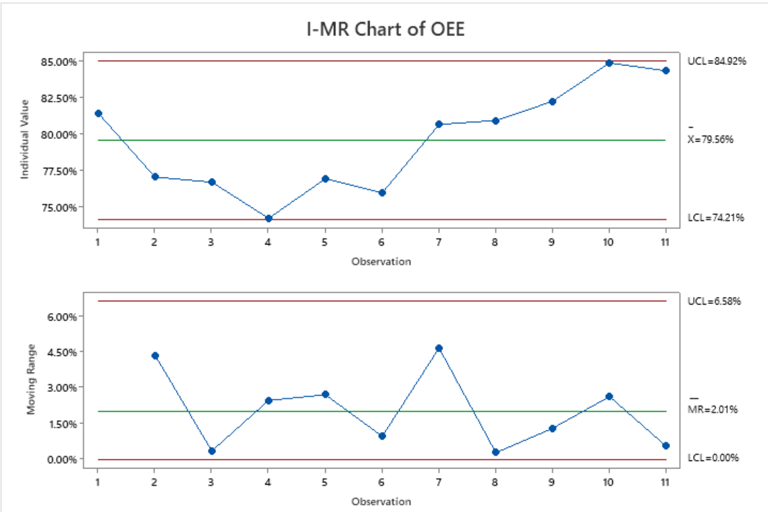


Chart 18: I-MR control chart of OEE index for the first 12 months.

Method

μ_1: population mean of OEE when Formul = 1
μ_2: population mean of OEE when Formul = 2
Difference: $\mu_1 - \mu_2$

Equal variances are assumed for this analysis.

Descriptive Statistics: OEE

Formul	N	Mean	StDev	SE Mean
1	6	0.767	0.168	0.069
2	22	0.720	0.145	0.031

Estimation for Difference

Difference	Pooled StDev	95% CI for Difference
0.0464	0.1498	(-0.0955, 0.1882)

Test

Null hypothesis $H_0: \mu_1 - \mu_2 = 0$
Alternative hypothesis $H_1: \mu_1 - \mu_2 \neq 0$

T-Value	DF	P-Value
0.67	26	0.508

Figure 3. The results of the two-way hypothesis test of the independence of the averages of two communities.

Method

Null hypothesis	All means are equal
Alternative hypothesis	Not all means are equal
Significance level	α = 0.05

Equal variances were assumed for the analysis.

Factor Information

Factor	Levels	Values
Operator	3	A, B, C

Means

Operator	N	Mean	StDev	95% CI
A	5	726	399	(433, 1018)
B	5	642	277	(349, 934)
C	5	649.0	185.8	(356.4, 941.6)

Pooled StDev = 300.331

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
300.331	1.97%	0.00%	0.00%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Operator	2	21738	10869	0.12	0.888
Error	12	1082384	90199		
Total	14	1104122			

For 2-sample t, the hypotheses are as follows.

Null hypothesis

$H_0: \mu_1 - \mu_2 = \delta_0$	The difference between the population means ($\mu_1 - \mu_2$) equals the hypothesized difference (δ_0).

Alternative hypothesis

Select one of the following alternative hypotheses.

$H_1: \mu_1 - \mu_2 \neq \delta_0$	The difference between the population means ($\mu_1 - \mu_2$) does not equal the hypothesized difference (δ_0).
$H_1: \mu_1 - \mu_2 > \delta_0$	The difference between the population means ($\mu_1 - \mu_2$) is greater than the hypothesized difference (δ_0).
$H_1: \mu_1 - \mu_2 < \delta_0$	The difference between the population means ($\mu_1 - \mu_2$) is less than the hypothesized difference (δ_0).

Means

Operator	N	Mean	StDev	95% CI
A	5	726	399	(433, 1018)
B	5	642	277	(349, 934)
C	5	649.0	185.8	(356.4, 941.6)

Pooled StDev = 300.331

Figure 4. The test of the equality of the averages of several communities to check the significance of the average difference in 3 shifts.

Regression Equation

Plan Stoppage-1 = 10.02 + 0.9975 CO + 0.9828 Hd + 0.1540 Aj

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	10.02	7.30	1.37	0.179	
CO	0.9975	0.0266	37.56	0.000	1.03
Hd	0.9828	0.0102	96.63	0.000	1.01
Aj	0.1540	0.0816	1.89	0.068	1.02

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
13.5712	99.69%	99.66%	99.63%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	1888094	629365	3417.15	0.000
CO	1	259839	259839	1410.80	0.000
Hd	1	1719596	1719596	9336.58	0.000
Aj	1	656	656	3.56	0.068
Error	32	5894	184		
Total	35	1893988			

Fits and Diagnostics for Unusual Observations

Obs	Plan Stoppage-1	Fit	Resid	Std Resid	
7	315.00	339.65	-24.65	-2.01	R
74	690.00	696.76	-6.76	-0.64	X
78	1465.00	1465.57	-0.57	-0.08	X

R Large residual
X Unusual X

Response is Unplaned Stoppage-1

36 cases used, 45 cases contain missing values

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	CO	Hd	Aj
1	6.4	3.6	0.0	0.7	161.50		X	
1	1.2	0.0	0.0	2.5	165.93			X
2	7.7	2.1	0.0	2.3	162.81		X	X
2	7.4	1.8	0.0	2.3	163.01	X	X	
3	8.4	0.0	0.0	4.0	164.66	X	X	X

Figure 5. Regression test of scheduled stops in the first stage.

Regression Equation

Plan Stoppage 1 = 20.61 + 1.0006 CO + 1.0056 Hd - 0.0453 Aj

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	20.61	6.25	3.30	0.002	
CO	1.0006	0.0311	32.20	0.000	1.08
Hd	1.0056	0.0142	70.98	0.000	1.02
Aj	-0.0453	0.0644	-0.70	0.485	1.09

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
16.0055	99.15%	99.10%	99.01%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	1521538	507179	1979.81	0.000
CO	1	265535	265535	1036.54	0.000
Hd	1	1290652	1290652	5038.16	0.000
Aj	1	127	127	0.50	0.485
Error	51	13065	256		
Total	54	1534603			

Fits and Diagnostics for Unusual Observations

Obs	Plan Stoppage 1	Fit	Resid	Std Resid	
2	350.00	302.84	47.16	3.09	R
71	1028.00	1022.76	5.24	0.44	X
83	1153.00	1163.45	-10.45	-0.91	X
101	375.00	371.10	3.90	0.36	X

R Large residual
X Unusual X

Response is Plan Stoppage 1

73 cases used, 43 cases contain missing values

Vars	R-Sq	R-Sq (adj)	R-Sq (pred)	Mallows Cp	S	Ms	MQ	Bd
1	4.6	3.3	0.0	4.3	224.69	X		
1	1.7	0.3	0.0	6.6	228.14			X
2	9.1	6.5	0.3	2.9	220.96	X		X
2	5.2	2.5	0.0	5.9	225.57	X	X	
3	10.3	6.4	0.0	4.0	221.09	X	X	X

Figure 6. Regression test of scheduled stops in the second stage.

Regression Equation

Unplaned Stoppage-1 = 237.0 + 0.623 Bd + 1.244 Ms + 1.615 MQ

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	237.0	53.9	4.40	0.000	
Bd	0.623	0.451	1.38	0.175	1.24
Ms	1.244	0.313	3.98	0.000	1.23
MQ	1.615	0.520	3.10	0.003	1.08

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
104.948	45.16%	41.05%	32.39%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	362827	120942	10.98	0.000
Bd	1	21006	21006	1.91	0.175
Ms	1	174239	174239	15.82	0.000
MQ	1	106116	106116	9.63	0.003
Error	40	440562	11014		
Total	43	803389			

Fits and Diagnostics for Unusual Observations

Obs	Unplaned Stoppage-1	Fit	Resid	Std Resid	
15	464.0	459.3	4.7	0.05	X
26	775.0	543.1	231.9	2.34	R
70	105.0	303.6	-198.6	-2.06	R
73	689.0	696.0	-7.0	-0.12	X

R Large residual
X Unusual X

Figure 7. Regression test of unplanned stops in the first stage.

Regression Equation

Unplaned Stoppage 1 = 324.0 + 0.16 MQ + 0.667 Ms + 0.786 Bd

Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	324.0	58.7	5.52	0.000	
MQ	0.16	1.05	0.15	0.882	1.07
Ms	0.667	0.346	1.93	0.058	1.15
Bd	0.786	0.115	6.86	0.000	1.14

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
141.217	40.98%	38.41%	30.82%

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Regression	3	955323	318441	15.97	0.000
MQ	1	440	440	0.02	0.882
Ms	1	74215	74215	3.72	0.058
Bd	1	939658	939658	47.12	0.000
Error	69	1376020	19942		
Total	72	2331343			

Fits and Diagnostics for Unusual Observations

Obs	Unplaned Stoppage 1	Fit	Resid	Std Resid	
17	784.0	908.1	-124.1	-1.01	X
46	219.0	355.2	-136.2	-1.07	X
77	1232.0	1112.0	120.0	1.17	X
93	833.0	434.6	398.4	2.84	R
94	950.0	887.8	62.2	0.49	X
102	1254.0	364.4	889.6	6.55	R

R Large residual
X Unusual X

Figure 8. Regression test of unplanned stops in the second stage.

Authors contributions
All authors have contributed equally to prepare the paper.

Availability of data and materials
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflict of interests
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Open access

References

[1] A. A. P. M. N. Esfandiari. "Evaluation and improvement of production processes using six sigma methodology.". *Journal of Development and Transformation Management*, pages 75–84, 2009.

[2] B. Y. Lei Geng. "Effects of PDCA cycle management on patients with acute myelocytic leukemia receiving decitabine combined with low dose idarubicin and cytarabine.". *International Journal of Industrial Chemistry (IJIC)*, **13**(1):1–11, 2022.

[3] S. N. Hasan Ali. "Six Sigma review of mechanisms to achieve TQM.". *Publications of the Aerospace Industries Organization*, 2008.

[4] E. A. F. M. O. O. O. M. Ikumapayi. "Six sigma versus lean manufacturing - An overview.". *Materials Today: Proceedings*, **26**(2):3275–3281, 2020.

[5] S. D. L. N. Ivana Tita Bella Widiwati. "The implementation of Lean Six Sigma approach to minimize waste at a food manufacturing industry.". *Journal of Engineering Research*, **12**(2), 2024.

[6] R. S. B. Y. Raman. "Defect reduction in a capacitor manufacturing process through Six Sigma concept: a case study.". *Mgt. Sci. Let.*, **9**:253–260, 2019.

[7] G. F. M. "Quality planning, and analysis.". *New York: McGraw-Hill*, 1991.

[8] M. C. M. G. L. F. F. J. G. P. L. Bonome. "Lean, six sigma and lean six sigma in the food industry: a systematic literature review.". *Trends Food Sci. Technol*, **82**:122–133, 2018.

[9] T. T. R. K. Beemaraj. "Six sigma concept and dmaic implementation.". *Int. J. Bus. Manage. Res.*, **3**:111–114, 2018.

[10] A. F. A. Z. N. T. A. Flifel. "Identification and selection of Six Sigma projects.". *Journal of Process Mgt. - New Tech. Int.*, **5**(2):10–17, 2017.

[11] K. C. S. Nagi. "Applying Six Sigma techniques to improving the quality of eLearningcourseware components - A case study.". *IEEE Int. Conference on Mgt. of Innovation & Tech.*, pages 275–280, 2010.

[12] S. I. Y. D. C. C. W. H. L. H. Chang. "Applying Six Sigma to the management and improvement of production planning procedure's performance.". *Total Quality Mgt.*, **23**(3):291–308, 2012.

[13] S. F. V. S. d. A. I. Antônio Carlos Pacagnella Junior. "Efficiency analysis of Lean Six Sigma projects: insights for selection and prioritisation.". *Total Quality Management & Business Excellence*, **35**(2):1–31, 2024.

[14] J. A. Alessandro Laureani. "Leadership and Lean Six Sigma: a systematic literature review.". *Total Quality Management & Business Excellence*, **30**(1): 53–81, 2017.

[15] R. D. Snee. "Why should statisticians pay attention to Six Sigma?.". *Quality Progress*, **32**(9):100–103, 1999.

[16] Venkateswaran N. P. P. "Impact of Six Sigma methodological practices in manufacturing unit - an experimental study.". *Arabian Journalof Business and Mgt. Review (Oman Chapter)*, pages 1–11, 2018.

[17] Srinivasan K. M. S. D. S. S. C. "Enhancement of sigma level in the manufacturing of furnace nozzle through DMAIC approach of Six Sigma: a case study.". *Production Planning & Control*, **27**(10):810–822, 2016.

[18] A. Y. "An analysis of Six Sigma at small vs. large manufacturing companies.". *University of Pittsburgh, Pennsylvania, USA*, 2005.

[19] Chang K. K. W. F. "Applying Six Sigma methodology to collaborative forecasting.". *Int. Journal of Advanced Mfg. Tech.*, **39**(1033-1044):9–10, 2017.

[20] A. W. T. N. F. Shokri. "Investigating the readiness of people in manufacturing SMEs to embark on Lean Six Sigma projects an empiricalstudy in the German manufacturing sector.". *Int.Journal of Opr. & Production Mgt*, **36**(8):878–850, 2016.

[21] P. G. N. L. C. E. Le Mahieu. "Six Sigma in education.". *Quality Assurance in Edu.*, **25**(1):91–108, 2017.

[22] P. F. "Does Six Sigma work in service industries?.". *Quality Progress*, **38**(9):55–60, 2005.

[23] R. B. S. S. G. A. T. S. R. Anand. "Six Sigma-based approach to optimize deep-drawing operation variables.". *Int. Journal of Production Research*, **45**(10): 2365–2385, 2006.

[24] Y. S. J. S. J. S. K. S. P. V. Khawale. "Implementation of Six Sigma methodology for piston rod manufacturing.". *GlobalResearch and Dev. Journal for Eng.*, **2** (3):14–18, 2017.

[25] M. S. K. I. O. E. Jaffal. "Critical success factors for Six Sigma implementation in Gaziantep carpet companies.". *Industrial Eng. Let.*, **7**(2):83–92, 2017.

[26] M. S. Y. R. A. Almasarweh. "The effect of using Six Sigma methodologies on the quality of health service: a field study at Prince Hashem hospital/city of Aqaba.". *Journal of Social Sci.*, **3**(5):396–407, 2016.

[27] S. S. P. M. More. "Implementation of QMS with ISO in the Indian textile industry for improvement in performance.". *Journal of Mechatronics and Intelligent Mfg*, **3**(4):1–4, 2011.

[28] G. N. T. G. S. R. Purnama. "Increasing the implementation of environmental management systems based ISO 14001 with the Six Sigma: case study method in a manufacturing industry.". *Int. Journal of Research in Eng., Sci. and Mgt*, **2**(1):103–106, 2019.

[29] P. K. D. Kausik. "DM make up water reduction in thermal power plant using Six Sigma DMAIC methodology.". *Journal of Sci. & Industrial Research*, **67**: 36–42, 2018.

[30] A. F. A. Gerger. "Use of Six Sigma method as a process improvement technique: a case study in aerospace industry.". *Academic Journal of Sci.*, **6**(1):191–202, 2016.

[31] H. H. P. A. N. Aris Trimarjoko. "Consistency of DMAIC phases implementation on Six Sigma method in manufacturingand service industry: a literature review.". *Management and Production Engineering Review*, **11**(4):34–45, 2020.

[32] J. L. A.-H. G. S. C. J.-M. E. B.-F. J. L.-B. J. Garc´ıa-Alcaraz. "Mediating role of the Six Sigma implementation strategy and investment in human resources in economic success and sustainability.". *Sustainability*, **10**:1–21, 2018.

[33] P. T. "The Six Sigma handbook.". *USA: McGraw-Hill Companies*, 2003.

[34] P. K. P. Rana. "Initiatives of Six-Sigma in an automotive ancillary unit: a case study.". *Mgt. Sci. Let.*, **8**: 569–580, 2018.

[35] A. T. K. Chakraborty. "Case study analysis of Six Sigma implementation in service organizations.". *Business Process Mgt. Journal*, **18**(6):992–1019, 2012.

[36] H. D. M. J. R. J. V. T. S. S. De Koning. "Generic Lean Six Sigma project definitions in financial services.". *Quality Mgt. Journal, QMJ*, **15**(4):32–45, 2008.

[37] D. Stamatis. "Zeolitic imidazolate framework/-graphene oxide hybrid nanosheets functionalized thin film nanocomposite membrane for enhanced antimicrobial performance Bart Van der Bruggen.". *ACS Appl Mater Inter*, **8**(38):25508–19, 2016.

[38] İ. T. A. M. G. Erdal Yabalak. "Multi-response central composite design of the mineralization and removal of aniline by subcritical water oxidation method.". *International Journal of Industrial Chemistry (IJIC)*, **10**(2):97–105, 2019.

[39] J. P. J. D. T. Womack. "Lean thinking.". *New York: NY: Simon & Schuster*, 1996.

[40] B. Y. A. L. Gang. "Effects of PDCA Cycle Management on Patients with Acute Myelocytic Leukemia Receiving Decitabine with Low-Dose Idrobycin and Citarabine.". *International Journal of Industrial Chemistry (IJIC)*, **13**(1):1–11, 2022.