INTEGRATING MACHINE AVAILABILITY AND PREVENTIVE MAINTENANCE TO IMPROVE PRODUCTIVE EFFICIENCY IN A MANUFACTURING INDUSTRY.

ABSTRACT:
The major problems existing in the manufacturing industries is low productive efficiency and high frequencies of machine breakdown or downtime. However, equipment maintenance is momentous for improving productive efficiency, methods of integrating preventive maintenance (PM) and Machine availability into improving productive efficiency in manufacturing industries has attracted considerable attention. This work showcased a strategic process improvement plan that can be used to improve production process with low productive efficiency. Lean Six sigma (LLS) **(this long form is correct?)** is used as the method for implementation of a successful process improvement. A case study was used to show how a successful implementation of the Lean Six Sigma DMAIC approach, **(mention long form)** how statistical analysis can be used to identity defects in production line and this statistical analysis are used to significantly improve the production process. The Study is performed by conducting a qualitative and quantitative analysis using structured questionnaires, surveys, journals with the case a study that boasts of about 600 employees. Investigations showed that an average of 68% contributing to 79% productive efficiency apparently. However, the attempts of the decreasing downtime events and improving efficiency were based on scheduled maintenance checklist plan that is supported by the overall equipment effectiveness (OEE) benchmark as an indicator for affirming improvements. The linear regression model highlighted significant relationship between machine availability and productive efficiency. Proposed solutions using statistical analysis focused on sustainability, introducing a measurement model based on DMAIC criteria that demonstrated a significant improvement of 20% in machine availability, 44.3% in quality, 29.9% in productive efficiency and 57.4% OEE of the targeted case study. The research affirmed LSS **(mention long form)** as a sustainable solution for reducing defects for quality issues, variations, and efficiency in manufacturing industries, emphasizing ongoing resource optimization and continuous improvement in study variables. Findings from this paper shows that LSS this methodology is a catalyst for positive change, emphasizing continuous improvement and customer satisfaction (Need to improve this sentence)

Keywords: Machine Availability, Overall Equipment Effectiveness, Preventive Maintenance, Lean Six-Sigma, DMAIC, Efficiency.

1. INTRODUCTION

In the dynamic manufacturing world, achieving operational efficiency is a constant pursuit, Murali, [1]. Limited availability of a machine refers to the possibility that the system can still be used after a long period of operation. This is a key performance indicator for a repairable system. The level of availability is of great economic importance because it represents the provider's obligation to the service recipient regarding the reliability and maintainability of the equipment provided, as well as the service recipient's obligation to make timely and quality repairs. Increasing availability is a goal that must always be pursued, especially by maintenance systems, MĂRĂSCU-KLEIN *et al*, [2]. It is important to consider the impact of machine availability and how essential it is in production, especially when the target is to minimize total tardiness or downtime. To remain competitive in today's rapidly changing market landscape, every business must make achieving and maintaining operational efficiency a vital and continuous pursuit. With advancing competitors, fluctuating markets, constantly evolving technology, and ever-changing customer needs, companies must continually refine and optimize their operational processes to improve margins, reduce costs, and elevate quality, Fanquip, [3]. Machine and equipment breakdowns found in most manufacturing industries in developing countries like Nigeria and the adverse effects on the overall performance of the organization ranging from production loss, high production cost, obvious inability to meet production deadlines, poor company's reputation and loss of integrity which invariably reduces the share capital and the ability to compete with similar industries creates a window of research for possible remedies, R. Uche, *et al,* [4]. Reduction of downtime has a considerable effect in improving productivity and is a prerequisite for a profitable and flexible production, Nwanya *et al,* [5]. Maintenance is the major reason that results in machine unavailability, Chen, *et al,* [6]. Preventive maintenance (PM) actions are carried out to mitigate the failure risk and decrease the number of unexpected failures, Hu, *et al,* [7]. Productive efficiency has a goal of using the least number of resources to produce the most output. It can be applied to any industry that has limited resources and wants to improve its performance. Productive efficiency helps manufacturers to lower their costs, increase their profits, offer better prices, and satisfy their customers. Productive efficiency depends on various factors, such as technology, market, customer, and regulation.

Many researchers have explored developed a wide variety of models to evaluate the performance of production lines, and the optimizing operational management and productive efficiency and have made valuable contributions. However, less work has dealt with integrating machine availability and preventive maintenance to improve the productive efficiency in a manufacturing industry using Lean Six Sigma DMAIC methodology. Up-time improvement, waste reduction, and quality optimization are three important metrics for manufacturing industries to track and improve to enhance their capability and competitiveness. To realize these objectives, manufacturing industries have developed several methods to evaluate manufacturing processes and systems, Jin *et al*, [8]. For example, Nakajima proposed the Overall Equipment Effectiveness (OEE) to evaluate the utilization rate or efficiency of factory equipment, Nakajima, *et al,* [9]. Since its inception, OEE has been widely adopted to evaluate factory performance. Equipment precision and process health condition are highly related to OEE, hence, there has been an increasing interest in developing intelligent maintenance systems to maintain or improve OEE in order to effectively access equipment health condition and eventually predict and prevent unwanted degradation and failures.

A study by Todmal *et al,* [10] on "Analysis of machine breakdowns of cylinder block manufacturing line in order to improve the operational availability", explored the quality control tools such as the 5 why analysis, FMEA, Fishbone and cause and effect analysis to find the causes for any failure in a machine in other to improve operational availability. Their results showed that there was an increase in operational availability but it didn't match up with the bench mark of the 85% OEE manufacturing standard.

Lazim *et al.*, [11] on "The Impact of Preventive Maintenance Practices on Manufacturing Performance: A Proposed Model for SMEs in Malaysia" conducted a study that proposed a new research framework and hypotheses to examine the aforementioned relationships. The proposed framework includes PM team, PM strategy and planned maintenance as the determinants, while organizational capability serves as the moderating variable. Manufacturing performance was viewed in terms of innovation and financial factors. The proposed research direction and results were not targeted to improve productive efficiency of the system which creates a gap to adopt the lean six sigma to improve productive efficiency.

Ota, *et al,* [12] explored the optimization of a group sort of generation and operational administration in an aluminum company employing an incline fabricating framework. The operation and generation framework of the case think about company runs in different segments, which led to squander within the framework, ruining the company's capacity to meet client request. The group recognized the sorts of squander created by the case ponder company through operational information examination and surveys. Incline fabricating methods such as eight dangerous squanders, Heijunka, takt time, 5S approach, quality instrument administration, esteem stream mapping, Kaizen, Kaban, Gemba, and best and bottom-level inclusion were utilized to oversee the squander. The discoveries uncover absconds in stock, transportation, holding up times, and undiscovered thoughts of workers, all of which essentially affect the company's performance, these discoveries, however, did not capture the Lean Six Sigma DMAIC methodology for process improvement in the overall equipment efficiency OEE.

Masemola *et al.*, [13], identified inventory, transportation, and defects as production process factors affecting a South African company using lean manufacturing tools (5S, Standard Work, and Kanban). The problems stemmed from various areas of the company. Based on the results, not only was the production and operation of the company improved, but the research findings also offer valuable insights for leaders in the manufacturing industry to identify performance gaps and apply lean six sigma methodology to improve productive efficiency in manufacturing industries.

Tejas, *et al*, [14] on "Machine Operational Availability Improvement by Implementing Effective Preventive Maintenance Strategies - A Review and Case Study" in his research discovered, the main problem faced in automobile engine cylinder block manufacturing line is that the downtime still occurs even though after maintenance activities are carried out. Therefore, the available activities of preventive maintenance (PM) need to be improved and simplified. The main objective for his study was to reduce the machines downtime on engine cylinder block production line by analyzing and improving the available PM schedule and thus improve operational availability of machines. His results showed that was 4% to 9% increase in machine availability which did not solve the overall productive efficiency of the operational equipment.

Although productivity improvements have been shown to be beneficial in a number of industries, the oil and gas industry has not given it much attention. (Need to improve this sentence). By examining the integration of machine availability in the petroleum industry to improve productive efficiency in manufacturing industry, this research seeks to close this gap. (Gap is not identified from Literature review)

Following table, may use for Literature gap.

Sr No	Author, year	Type of Industries	Methodology/tool applied	Improvement in Productivity
1				
2				
14				
15				

The petroleum industry, which was the subject of this study, has been dealing with issues like low productive efficiency, production disruptions brought on by machine failure, and low customer satisfaction as a result of subpar products. Its manufacturing and operation system's intricacy, which spans several sectors, has impeded its overall performance and contributed to the observed inefficiencies.

2. MATERIALS AND METHODS

Materials used in the course of this research are in two phases, the phase I involves the instruments used to record machine performance during operations such as the uptime and downtime in hours, mean time between failures, meantime to repair, efficiency rates per shift, day, week and at monthly intervals.
Phase II includes the targeted equipment (OCME Filling Machine) used as a case study in this research study and mode of operation. – Good

2.1 Background of the Case Study and System Description

This research work focuses on a lubricant and chemical manufacturing industry situated at KM 62 Lagos-Ibadan Expressway Sagamu, Ogun State Nigeria, they are an integrated energy company that operates in various segments of the oil and gas industry. They are primarily engaged in manufacturing, marketing and distribution of lubricants and chemicals; trades in crude and operates a network of filling stations. It also plans to expand into the midstream and upstream of the energy sector. Also, they produce lubricants and petrochemical products for the maritime and energy sectors. This study seeks to address improve productive efficiency by integrating machine availability and preventive maintenance using the Lean Six Sigma DMAIC techniques. Fig. 1 shows the methodology flow chart of the study.

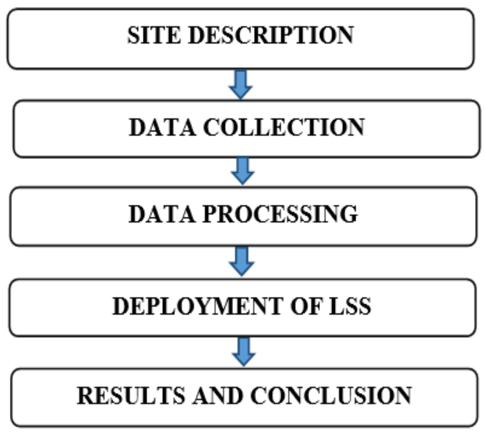


Fig.1 Research Methodology (Provide word figure/editable, second give various data collection and data processing methods/ tools in this line diagram, third what is mean by LSS? Don't write short forms in the diagrams/tables)

2.1 Research Scope and Objectives

The aim of this ~~research work is precisely on~~ is to integrate machine availability and preventive maintenance to improve productive efficiency of the lubricant and chemical manufacturing industry specifically on the OCME Filling machine (HYDRA 100 80 20) used during production with its operation is to fill processed lubricants into the containers for distribution by deploying Lean Six Sigma (DMAIC) techniques. ~~to identify machine availability, quality and performance affecting the efficiency, and recommend a preventive maintenance action plan for continuous improvement.~~

2.2 Data Collection

The research employs a combination of methods, including literature reviews, questionnaires, and data collection instruments and processes. This involves weekly and monthly report of machine performance, company journals of annual reports, surveys, and seminar materials, historical reports etc. were used to collect data that enabled reliable quantitative data of the overall equipment and operational availability OCME Filling machine. Additionally, data collection on the equipment was taken for a period of 12 calendar month spanning from August 2021 through July 2022. However, the OCME filling machine has the following specification

2.3 Data Processing

This research study uses machine availability as the main calculation metric rather than using a machine utilization metric. Machine utilization metrics are more likely to have a negative effect on the production line and could increase the likely hood of overproducing. Machine availability was found to be a better metric to consider for this study to relate how effective a machine or an equipment is in a production process as it has to do with productive efficiency of a manufacturing industry. Below are the current data obtained from the OCME filling during production time with their cycle time for each unit produced and how they were processed and analyzed.

Table 1. Filling Machine OCME (HYDRA 100 80 20) Information.

S/N	Details	Information
1	Manufacturer	OCME - ITALY
2	Manufacturing Year	2009
3	Machine Model	HYDRA 100 80 20
4	Machine Function	Filling
5	Maximum Speed	56, 000 Bottles/Btch
6	Number of Filling Valves	70 No's
7	Machine Serial Number	0800095A01
8	Production Line	Line #4
9	Machine Serial Number	0800095A01
10	Machine Capacity	80 liters/Min

Data Credit: www.masnai.com/en/filling-maachine-ocme-hydra-100-80-20-gt2112082348.html

a. Machine Availability

Machine Availability is given as

$$Machine\ Availability = \frac{ActualRunningtime}{TotalOperatingtime} x \frac{100}{1} \quad (1)$$

$$MTBF = \frac{TotalNo.ofOperatingTime}{No.of failures} \quad (2)$$

$$MTTR = \frac{TotalOperatingTime}{No.of Repairs} \quad (3)$$

b. Productive Efficiency:

To process the data for Productive Efficiency, the machine specifications were utilized to compute the information shown in the table below, productive efficiency is given as

$$Productive\ Efficiency = \frac{ActualOutput}{StandardOutput} x \frac{100}{1} \quad (4)$$

It is observed from the machine specifications that the maximum possible output or Standard Output:

Maximum speed is 56,000 bottles/batch (Machine Specification), the working hours available in August: 567.6 Hours
Hence, maximum bottles/hour = 56,000/batch x (1 batch/hour) = 56,000 bottles/hour

Standard Output or Maximum Possible Output is given as

$$MaximumSpeedperbatchxNo.ofworkingdays \qquad (5)$$

Therefore, for 567.6 working hours in August,

Maximum possible bottles = 56,000 x 567.3 = 31,768,800

Actual output is given as: $No.ofbottlesfilledxNo.ofworkingdays - Timelost$ (6)
50,000 bottles x (1 batch/hour) x 567.3 – 176.7 = 28,364,823

Therefore, Productive Efficiency = Actual Output/Maximum Possible Output x 100

$$\frac{28,364,823.}{19,855,323} x \frac{100}{1} = 62.5\%$$

c. Quality Rate

Defects—including those requiring rework—are assessed based on quality. Parts that require adjust or are made to substandard benchmarks are all considered within the setting (OEE) of quality.
However, Quality is given as

$$\text{Quality} = \frac{GoodCount}{TotalCount} \qquad (7)$$

Observations made during production time

i. Machine ran at an average productive efficiency of 89.3% for August
ii. 8 batches were rejected for quality issues in the month
iii. 56,000 bottles maximum per batch (given)
iv. Total 25.7 batches produced in August

Quality Rate Calculation:

Batches rejected = 8, Bottles per batch = 56,000

Total bottles rejected = 8 x 56,000 = 448,000

Total bottles produced = 25.7 x 56,000 = 1,439,200

Quality Rate Percentage = (Total Produced - Rejected) / Total Produced x 100

$$\frac{1,439,200-444,000}{1,439,200} x \frac{100}{1} = 69.1\%$$

d. Machine Performance Rate:

Actual Output = Total Batches x Batch Size x Productive Efficiency % (8)

= 27.6 batches x 56,000 bottles/batch x 62.5% Efficiency

= 138,022,080 bottles

Machine Performance = Actual Output / Maximum Possible Output x 100

$$\frac{138,022,080}{27.6x56,000} x \frac{100}{1} = 62.5\%$$

e. $$OEE = \text{Availability} \times \text{performance rate} \times \text{quality} \times 100\% \tag{9}$$

However, from information gathered from surveys, questionnaires and processed shows that the trends from the **Table 2** shown below, displays a poor key performance indicator (KPI) as they contribute to low productive efficiency. The annual average shows that it takes 182.3 hours before it breaks down, while it takes an annual average of 56.3hours to repair the OCME filling machine at every breakdown which leads to a 69% machine availability annually. Thus, this reflected to the poor performance of the machine which was at 65%. However, the quality of products was (In complete sentence)

Table 2. Current Data Obtained from the OCME Filling Machine (give the all borders for all tables)

Month	MTBF (Hrs.)	MTTR (Hrs.)	MA (%)	PE (%)	Quality (%)	ME (%)	OEE (%)
Aug.	186	44.2	76%	62.5	69	62.5	32.8
Sept	144	45	69%	54.5	67	54.5	20.4
Oct	248	71.3	71%	71.4	17	71.4	0.5
Nov	144	45	69%	62.5	91	62.5	38.1
Dec	148.8	65.1	56%	68.7	61	68.7	1.1
Jan	240	66	73%	73.7	82	73.7	43.3
Feb	134.4	33.6	75%	77.1	60	77.1	28.9
Mar	248	93	63%	58.0	76	58.0	17.2
April	180	45	75%	80.4	63	80.4	37.7
May	186	41.9	78%	44.6	75	44.6	25.8
June	180	60.8	66%	58.2	49	58.2	1.7
Jul	148.8	65.1	56%	76.8	83	76.8	26.4
Avg.	**182.3**	**56.3**	**69%**	**65%**	**49.7%**	**66%**	**22.8%**

Data Collected (Why this in capital?) is analyzed to identify patterns, trends, and areas for improvement. Findings are reported as shown in the **Table 2** above with recommendations for improving the productive efficiency and the overall equipment effectiveness (OEE).

2.4 Deploying the Lean Six Sigma (DMAIC) Techniques

Utilizing the strategy from Incline Six Sigma, it gives a sound pathway to fathoming an issue of destitute machine accessibility inside a fabricating prepare. Incline Six Sigma will be utilized as the essential source of instruments strategy for execution of an effective handle enhancement. The DMAIC approach drives the problem-solving endeavors by: characterizing the issue, capturing information and measuring the standard for the venture, analyzing the current state information and issues for preparing advancements, actualizing advancement changes, and approve the outcomes about and apply control measurements to the method.

Table: 3 Pareto Analysis: Causes of downtime in OCME Filling machine (give the all borders for all tables)

S/N	Defects	Frequency	Percentage	Cumulative (%)
1	Unscheduled Maintenance	350	350	64%
2	Operator Error	76	426	78%
3	Tooling Changeover	50	476	87%

4	Power Loss	27	503	92%
5	Poor Inventory	20	523	96%
6	Material Shortage	12	535	98%
8	Inspection time	7	542	99%
9	loading and unloading	3	545	100%
	Total	**545**		

i. Define Phase: In the define phase, Lean Six Sigma tools identified key improvement areas by analyzing historical data. A Pareto chart, based on the 80/20 rule, revealed that 20% of causes create 80% of downtime, highlighting priority areas for improvement. This analysis helps make effective decisions by focusing on the most impactful factors.

The data follows a classic Pareto principle: a small number of causes (top 3) contribute to the vast majority (87%) of downtime**.** The top cause alone, unscheduled maintenance, is responsible for a whopping 64%. Therefore, improvement efforts should prioritize the "vital few" top causes, with the most benefit potentially coming from tackling just the top one. The remaining causes have minimal impact. Focusing on the biggest hitters will yield the most significant reductions in downtime.
However, Adopting the Kano model by Kano, [15], Voice of Customer (VOC), suggests that customer feedback was gathered and analyzed through the Kano Model to understand what features and improvements are most important for customer satisfaction. This helps the manufacturing industry prioritize their efforts on what truly matters to their customers.

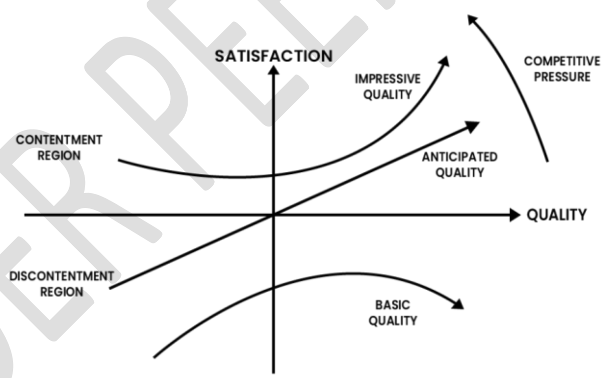


Fig. 2. Kano Model for Voice of Customer

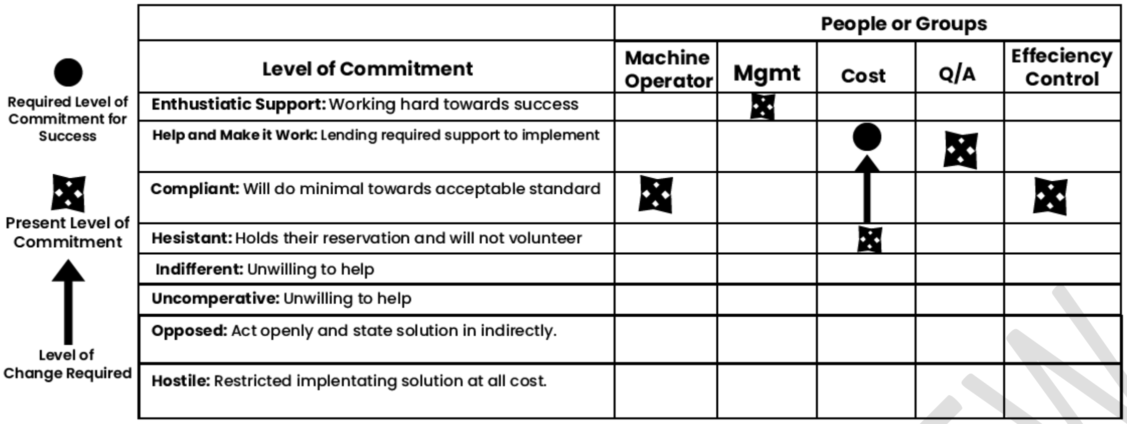


Fig. 3. Stakeholder Analysis (give the citation for this figure)

However, Data from the Stakeholders was collected and an investigation was performed to determine how willing each of them would coordinate with the advancement handle. Looking at **Fig. 3**, below, the Stakeholders in petroleum and gas manufacturing industry PLC comprises of the organizational directors and the operational directors such as machinist/Operator, quality specialist, generation director, generation facilitator, and an inner client. They felt the extension wasn't their duty and didn't see themselves as significant for advancement. After a clear clarification of the project's reason and the key part of the inside client played, their viewpoint moved.

ii. Measure Phase: In the measure phase, the baseline data will be established which will lead the maintenance team in a direction to focus improvement efforts. This phase will clearly define the process and quantify the current machine availability. After identifying the current state of the equipment to be measured, the baseline for the machine availability and productive efficiency was addressed.

a) In order to maintain focus on the process improvements rather than the customer's needs, the important Critical Tree Quality (CTQ) Hessing, 2014 [16] in Fig. 3 was utilized. The mean time between failures and the mean time to repair were determined to be the CTQs of machine availability.

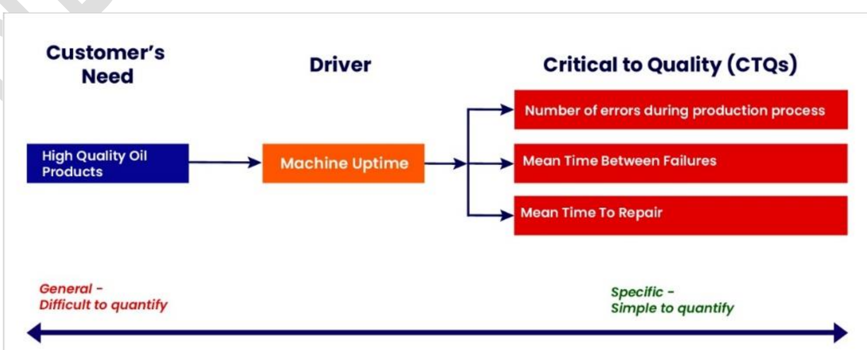


Fig. 4. Critical to Quality Tree

b) Also, the SIPOC model by Simon, [17] provides the team with crucial information. By connecting suppliers, inputs, outputs, and customers with the process, the team can better understand what is required for the process to function. With this knowledge, the team can pinpoint places where information is currently lacking in efficiency. However, in order to illustrate and connect essential criteria to the process of improvement, the Suppliers, Inputs, Process, Output, and Customer (SIPOC) map was developed.

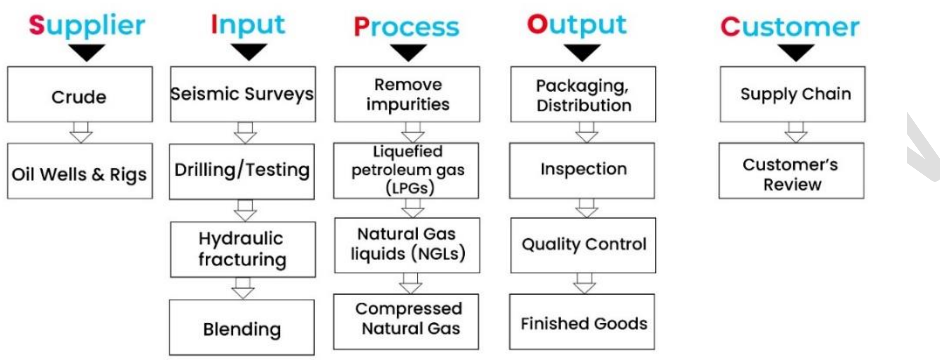


Fig. 5. SIPOC Map Process of the Lubricant Manufacturing industry

The manufacturing facility operates in three shifts per day, lasting eight hours each. The actual average output speed attained is five 56,000 bottles per batch. Setup, cleaning, breakdowns, and other downtime cost the company 1.9 hours per shift each day, for a total of 176.6 hours in August. Equation (10) is used to calculate Overall Equipment Effectiveness (OEE). OEE operates by dividing the causes of productivity losses into three primary categories: Availability, Quality and Performance. The availability factor calculates the lost productivity due to system failures. Eqn. (1) can be used to calculate availability by dividing actual production time by anticipated production. Furthermore, rates of quality and performance are expressed in equations (8) and (9) respectively.

In addition, one crucial area that every plant can improve on is efficiency and one of the best measures of efficiency is OEE, Hechtman, [18]. The key to this argument is that organizational efficiency has relevance for business sustainability.

A linear regression analysis in Statistical Package for Social Sciences (SPSS) and Microsoft Excel (MS Excel) was used to determine the relationship between machine availability and productive efficiency. Analyses were made, and graphs plotted accordingly. The test of hypothesis using regression models was decided on the following hypothesis.

i. **Null Hypothesis (H0):** There is no significant relationship between machine availability and productive efficiency. Any observed difference is due to chance.

ii. **Alternative Hypothesis (Ha):** There is a significant relationship between machine availability and productive efficiency. Observed differences are likely due to the influence of machine availability on productive efficiency.

Therefore, the regression equation model was employed to unveil the hidden relationship between machine availability and productive efficiency. The regression model is given as thus,

$$Y = mx + b \qquad (10)$$

Where Y = value of dependent variable while X = values of the independent variables.

In the above equation (10) the regression coefficient 'm and b' a constant or y intercept are mathematically determined by the least squares methods as

$$m = \frac{n\Sigma xy - \Sigma x\Sigma y}{n\Sigma x^2 - (\Sigma x)^2} \quad (11)$$

$$b = \frac{\sum y \sum x^2 - \sum y \sum xy}{n \sum x^2 - (\sum x)^2} \quad (12)$$

Where n = Number of data points available
Σx= sum of x – data points
Σy= sum of y – data points
Σxy= sum of the product of each set of x and y data points
However,
Intercept (b): Represents the base value of y when the independent variable (x) is zero.
Coefficient of X (m): Represents the steepness of the regression line, also known as the gradient.
Correlation Coefficient (R): Measures the strength and direction of the linear relationship between x and y. it is also known as the Pearson Correlation coefficient and is given by

$$r = \frac{n\Sigma xy - (\Sigma x)(\Sigma y)}{\sqrt{\left[n\Sigma x^2 - (\Sigma x)^2\right]\left[n\Sigma y^2 - (\Sigma y)^2\right]}} \quad (13)$$

In simple terms, R^2 tells us how well the regression line fits the data. A higher R^2 indicates that the model is better at capturing the true relationship between x and y.

Therefore, understanding and interpreting the Standard Error of the Estimates is crucial for evaluating the reliability and validity of any regression analysis.

$$Se = \sqrt{\frac{\Sigma y^2 - b\Sigma y - \text{mxy}}{n-2}} \quad (14)$$

However, Assessing PM activities, the MTBF, MTTR, PE and the OEE and Establishing a Base Line for Improvement.

However, from the **Table 2,** the Mean Time Between Failures (MTBF), Time to Repair (MTTR), and Machine Availability (MA) was accessed and it revealed that the MTBF has an annual average of 182.3 hours, with out-of-control points indicating potential issues, while MTTR showed high annual average of 56.3 hours, and further impacting on machine availability as it contributes to low productive efficiency. Machine Availability indicated an annual average of 69%, productive efficiency has an annual average of 65%, and quality of products has an annual average of 49% while OEE has annual average of 22.8% also confirming downtime the OCME filling machine. The combination of low MTBF and high MTTR significantly contributes to the poor MA and PE suggesting the need for improvement in both aspects. However, in order to assess preventive maintenance on machine availability and productive maintenance, OEE served as a powerful tool for assessing, measuring and improving manufacturing performance. It acts as both a benchmark for comparing a production asset to Industry standards, assessing how well the asset performs compared to the industry average. OEE functions as a baseline for tracking progress over time. By understanding and using OEE as a benchmark and baseline, manufacturers can effectively evaluate their performance and implement strategies to achieve world-class efficiency.
Comparatively, the ideal value for plant OEE is 100% which means all machines have zero downtime, full availability and are not making any non-conforming parts. Studies show that average OEE in the

manufacturing industry is about 60% whereas world class OEE is 85%, Anand, [19]. This implies that lubricant manufacturing industry was below average in production.

iii. Analyze Phase:

Poor machine availability due to frequent downtime and long repairs leads to sporadic and uncontrolled machine downtime as it contributes to low machine efficiency in the manufacturing industry. Rework and poor efficiency are caused by a cumbersome process. Analyzing non-value-added steps in the current process map will reveal key improvement opportunities. Cause-and-effect analysis revealed poor maintenance and operation as the main causes of low machine uptime. Quick wins ("just do it" fixes) will be implemented for immediate improvement, with further focus on maintenance and operation practices. It was advisable to perform a failure mode effect analysis to understand and improve the failure of the process. However, the Failure Mode and Effect Analysis (FMEA) revealed several unique causes contributing to unscheduled maintenance. Risks were assessed based on its: Severity: Impact on the customer. Occurrence: Frequency of the issue and Detectability: Ease of identifying the problem with recommended actions.

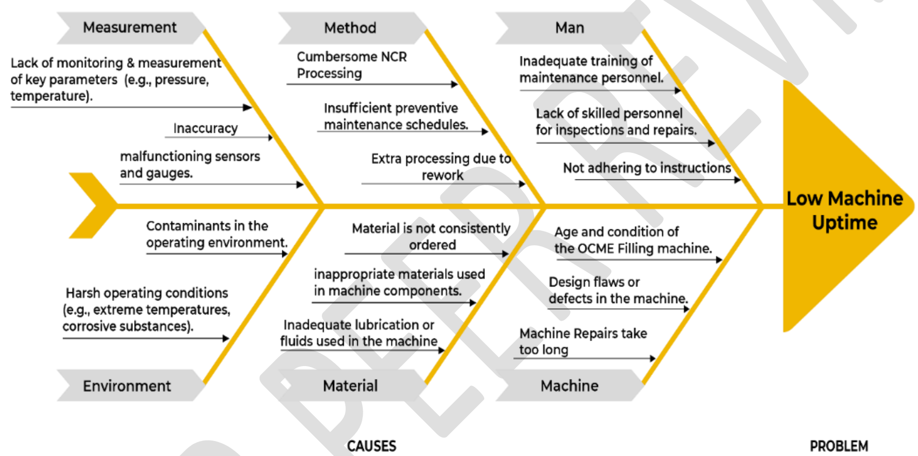


Fig. 6 Fishbone Diagram on the Low machine uptime of the OCME Filling Machine (Scope for the improvement in this diagram by adding sub-cause eg: Inaccuracy in measurement due to not skilled worker or not trained other sub-cause for Inaccuracy in measurement due to working environment etc)

iv. Improve Phase:

~~In the improve phase~~, In this phase, possible solutions came from the data in the measure and analysis phase. The best solution was tested, steps were taken to be a sure deployment of the new process and were implemented in a structured manner. The current state process map was reviewed for opportunities, and a new future state map was made to reflect a new process after improvements were made. A 5-step improvement plan was proposed, identify root causes behind the major themes from the fish bone and FMEA analysis, Address failure modes identified in the FMEA. Below is the preventive maintenance plan or framework for the OCME filling machine after performing a cause effect analysis and the failure mode effect analysis.

Table 4. Preventive Maintenance Schedule

Issue	**Preventive Maintenance Action**	**Frequency**	**Responsibility**
Lack of monitoring and measurement of key parameters	Implement a condition monitoring system to track key parameters such as pressure, temperature, and humidity.	Daily/Weekly	Maintenance technician
Insufficient preventive maintenance schedules	Develop and implement a preventive maintenance schedule based on the manufacturer's recommendations and historical data.	Monthly/Quarterly	Maintenance planner
Inadequate training of maintenance personnel	Provide training to maintenance personnel on the OCME filling machine, including proper operation, maintenance procedures, and troubleshooting.	Annually	Maintenance supervisor
Not following instructions	Develop and implement a standardized work instruction program for all maintenance tasks.	Ongoing	Maintenance supervisor
Malfunctioning sensors and gauges	Calibrate sensors and gauges regularly.	Monthly/Quarterly	Maintenance technician
Contaminants in the operating environment	Implement housekeeping procedures to control dust, dirt, and other contaminants.	Daily/Weekly	Production operator
Harsh operating conditions	Implement measures to control temperature, humidity, and other environmental factors.	As needed	Production supervisor
Inappropriate materials used in machine components	Use only the materials recommended by the manufacturer.	As needed	Maintenance planner
Design flaws or defects in the machine	Contact the manufacturer to report any design flaws or defects.	As needed	Maintenance supervisor
Inadequate lubrication or fluids used in the machine	Follow the manufacturer's recommendations for lubrication and fluids.	Monthly/Quarterly	Maintenance technician
Machine repairs take too long	Develop and implement a root cause analysis program to identify and address the underlying causes of machine failures.	Ongoing	Maintenance supervisor

The Preventive maintenance schedule and plan follows the TPM activities which is made evident by measuring the Overall Equipment Effectiveness (OEE). From research it was identified that the input factors such as man, machine and material and other factors such as the outputs comprised of production (P), quality (Q), cost (C), delivery (D), safety, health and environment (S), and morale (M) strives to improve the OEE by maximizing the output while minimizing the input. Hence, maintaining ideal operation conditions and running equipment effectively.

v. Control Phase:

In the control phase, a control strategy is developed to monitor the progress of the implementation for the future state. To control the process, control metrics are put in place to monitor the process. To control the process, control metrics are put in place to monitor the process. A daily management KPI board, seen in Figure 3.12, has four specific metrics to track. The metrics consist of Safety, Quality, Delivery, and Productivity. There are also three sheets used for tracking data.

3.0 RESULTS AND DISCUSSIONS

3.1 Correlation Between Machine Availability and Productive Efficiency.

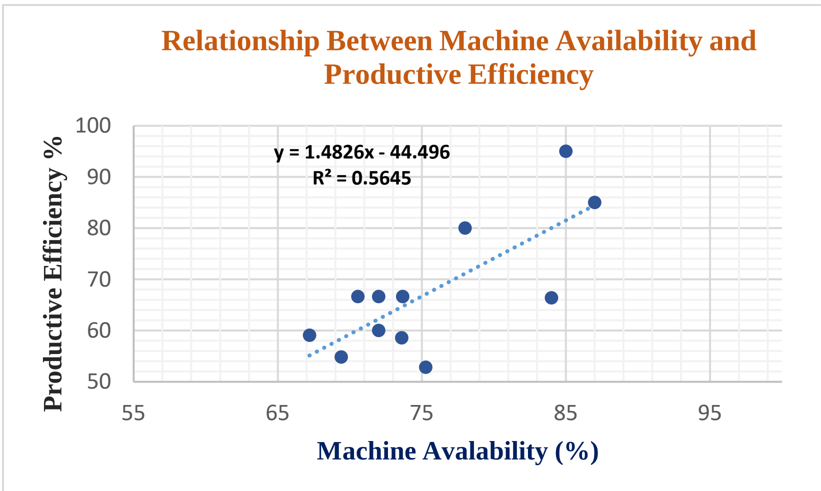


Fig. 7 Scatter Plot showing the relationship between Machine Availability and Productive Efficiency

From the Fig. 5 the linear regression Analysis of Machine Availability (MA) on Productive Efficiency (PE) has a value of 0.56 indicates a strong positive correlation between machine availability and productive efficiency, the slope of the regression line is 0.38, which means that for every 1% increase in machine availability, we can expect to see an increase of 0.9% in productive efficiency. The p-value of 0.004847325 is less than the significance level of 0.05, which means that the correlation is statistically significant. Therefore, we can reject the null hypothesis and conclude that there is a significant positive correlation between machine availability and productive efficiency.

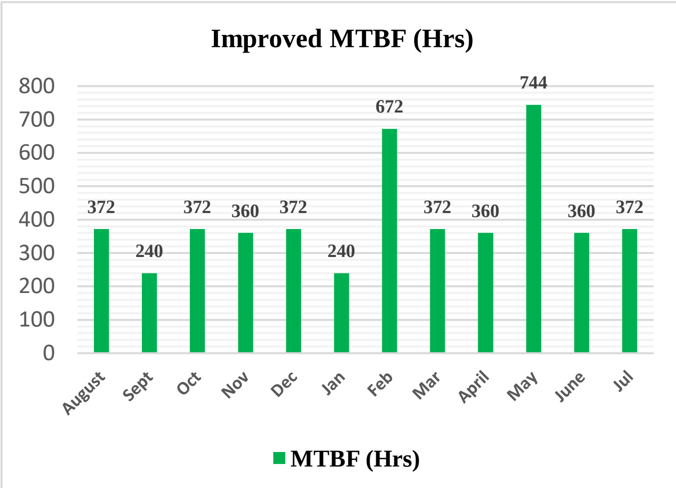


Fig. 8 MTBF Annual Average after deploying LSS techniques.

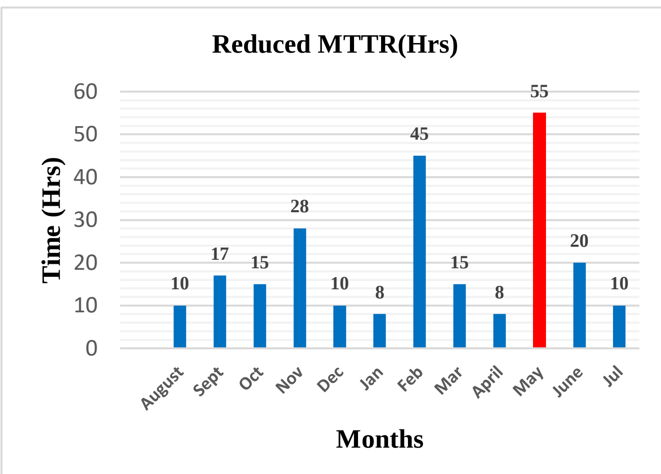
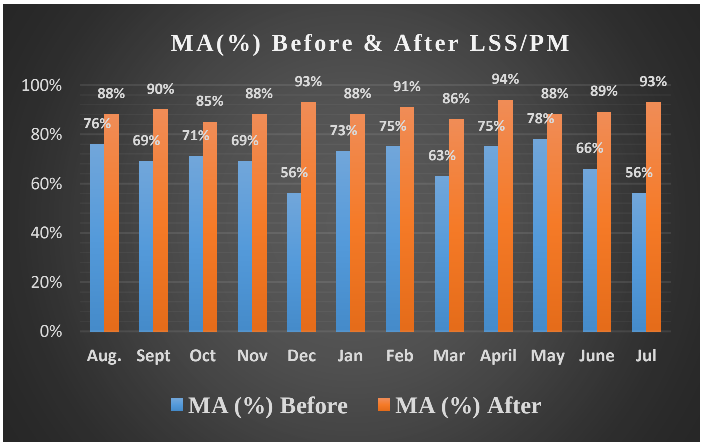


Fig. 9, MTTR Annual Average after deploying LSS techniques.

From **Fig. 8,** High Mean Time Between Failure (MTBF) increases machine availability, as it indicates a longer time before a machine fails or encounters breakdowns. After deploying the Lean Six Sigma and implementing the new preventive maintenance schedule, the MTBF increased on average by about 403 hours from the previous 182 hours. In May, there was no failure, which improved production time and efficiency, leading to higher machine availability, however this is an indicator of the effectiveness of preventive maintenance and repair processes. However, from **Fig. 9**, the average Mean Time To Repair (MTTR) was reduced on average from 56 hours to 20 hours, which made incidents to be resolved quickly as it freed up time and resources that could be used for other tasks. It further led to increased productivity and efficiency within the team and organization. The results shows that the reduced MTTR entailed higher customer satisfaction by minimizing the impact of incidents on their experience. It improved customer loyalty and retention.



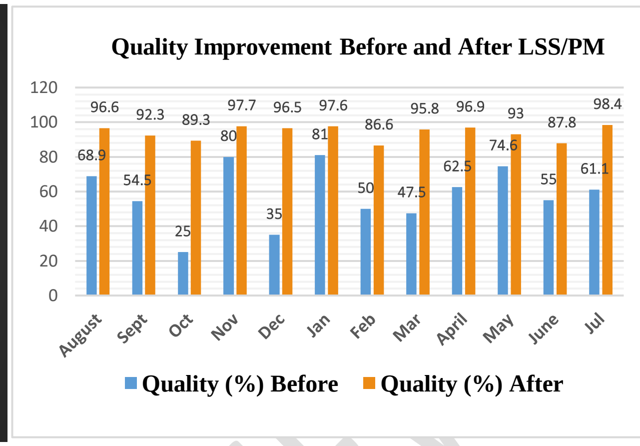
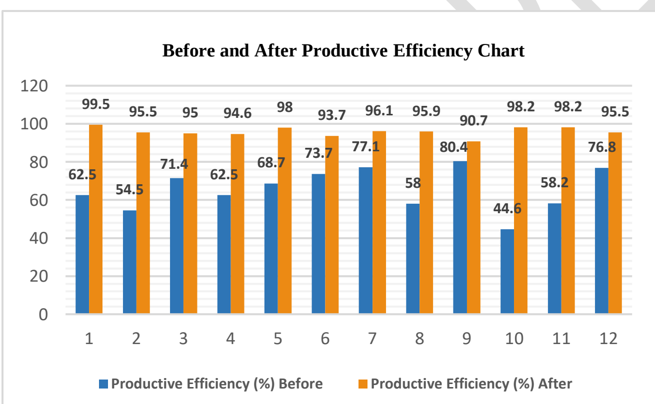


Fig. 10. Machine Availability before and After LSS/PM

Fig. 11. Quality Improvement Chart before and After LSS/PM

After the implementation of preventive maintenance in **Fig. 10**, the MA increased significantly and remained consistently in the high 80s. For example, in December before deploying the Lean Six Sigma Improvement phase, the machine availability was 56% but after deploying the Lean Six Sigma, machine availability increased to 93%, and the same went for other months, as shown in the bar chart. This chart suggests that the implementation of improved preventive maintenance schedule using a Lean Six Sigma approach was successful in improving machine availability. This approach helped to identify and eliminate the root causes of machine failures, as well as prevented future machine downtime during production. However, the quality of the product improved significantly and became much more consistent.

In **Fig. 10**, the quality of lubricant produced was never lower than 95.8% and was as high as 98.4% in July. This implied that there was an average improvement of 44.3% in quality of products produced withing the period of one year. However, the defects withing this period were significantly reduced. This summarizes the aim of the Lean Six Sigma in the improvement process.



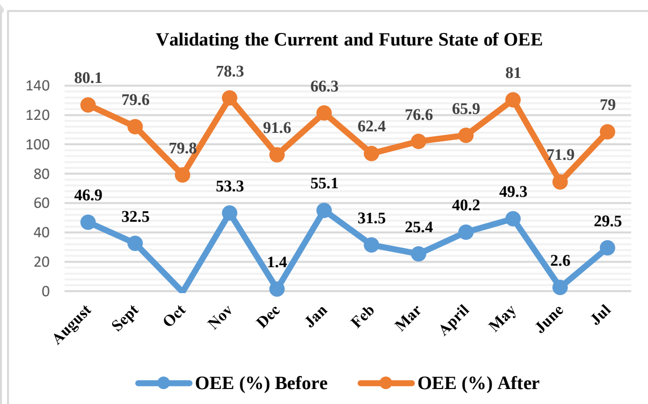


Fig. 12. Productive Efficiency after LSS/PM Schedule

Fig. 13. OEE before and after LSS/PM Schedule

The result in **Fig. 12**, shows that the productive efficiency of the manufacturing process has been steadily increasing over time. In August, the productive efficiency was at 92%. It then increased to 94.6% in September and 95.5% in October. In November, the productive efficiency reached 95.9%, and it continued to increase to 96.1% in December. By January, the productive efficiency had reached 98.2%. The graph result on **Fig. 13** shows that the OEE of the manufacturing process increased significantly after the new preventive maintenance was implemented using the Lean Six Sigma approach. Before preventive maintenance, the OEE was in the low 60s. However, after preventive maintenance, the OEE increased as high as 91% in December. The increase in productive efficiency has a number of benefits at ETERNA PLC, including increased production output, lower production costs, and improved profitability.

Below is the summary of results gotten before and after deploying Lean Six Sigma DMAIC method for improving productive efficiency of the manufacturing industry.

Table 5. Results showing metric improvements (give the all borders for all tables), Add graph for this table it will give clear picture/understanding to the reader/research

	Metric	*Average Value Before PM Schedule*	*Average Value After PM Schedule*	*Percentage Increase*
1.	MTBF	182.3 Hours	403 Hours	**220.7 Hours**
2.	MTTR	56.3 Hours	20 Hours	**36.3 Hours**
3.	MA	69%	89%	**20%**
4.	Quality	49.7%	94.0%	**44.3%**
5	Performance (PE)	65.7%	95.6%	**29.9%**
6.	OEE	22.8%	80.2%	**57.4%**

4. CONCLUSIONS (Try to write pointwise conclusions: to bullets. It is easy to read and understand)

~~Improving productive efficiency was carried out in a manufacturing industry in this study. In the course of this research, different methods were adopted: a case study was conducted on ETERNA PLC,~~ (Need to improve this statement) set of structured questionnaires was presented to the staff working in the manufacturing industry and oral interviews were conducted. The choice of an oil and energy is motivated by inseparable nature of raw material, process and product qualities variables which influence high productivity improvements in lubricant manufacturing. ~~Specific techniques were used~~ (name of that technic should be mention here in the conclusion section) to ensure the sustainability of this research work, focusing on the precise identification of problems, the implementation of improvements and the availability of machines within the manufacturing process. Lean Six Sigma methodologies and techniques were used to improve the process by integrating machine availability and planned preventive maintenance. By using the Lean Six Sigma DMAIC method, a systematic process is established that significantly improves the machine availability and preventive schedules of the process, leading to increased production. The data collected from the respondents were analyzed, and a linear regression analysis using statistical package for social sciences (SPSS) and Microsoft Excel (MS Excel) was also used to analyze how downtime affect machine performance, and quality of products produced.

From the OEE, a bench mark of 85% was considered a world standard for production in a manufacturing industry result from the analysis shows an 80.4% was achieved after deploying the Lean Six Sigma improvement process. This signifies a commendable improvement in the overall equipment effectiveness of ETERNA PLC. However, this study showed improvements in real projects using the OCME filling machine as a case study. Process improvements include a 20% increase in machine availability, 403 hours increase in the Mean Time Before Failure (MTBF), a 20-hour reduction in average mean time repair time (MTTR), a 44.3% quality improvement in the products produced and a 29% increase in productive efficiency (PE).

5. CONTRIBUTION TO KNOWLEDGE (No need of this section after conclusions)

~~One of the significant contributions of Lean Six Sigma to improve productive efficiency is the reduction of defects, minimizing downtime and operational errors. In an industry where the margin for error is minimal, the Six Sigma component of the methodology becomes particularly relevant. By systematically identifying and addressing the root causes of defects, manufacturing industries organizations can significantly enhance the quality of their outputs, leading to improved customer satisfaction and reduced rework.~~

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