DMAIC Application for Time-Based Operational Efficiency Improvement

[1]Adegoke E. Olusesan, [2]Bukola O. Bolaji, [3]Bayode J. Olorunfemi, [4]Emmanuel O. Omotosho
[1,2,3]Department of Mechanical Engineering, Federal University Oye-Ekiti, Ekiti State, Nigeria.
[4]Department of Mechanical Engineering, Federal University of Technology Akure, Ondo State, Nigeria.
olusesanadegoke@yahoo.com| bukola.bolaji@fuoye.edu.ng|bayode.olorunfemi@fuoye.edu.ng|omotosholuwagbemiga@gmail.com

Received: 24-JULY-2026; Reviewed: 25-MARCH-2026; Accepted: 30-AUGUST-2026
https://dx.doi.org/10.46792/fuoyejet.v11i3.1436

ORIGINAL RESEARCH

Abstract— Operational efficiency remains a critical determinant of productivity and competitiveness in manufacturing industries. This study applied Lean Six Sigma by using the Define-Measure-Analyze-Improve-Control (DMAIC) methodology to improve the operational efficiency of a sandwich biscuit packaging machine using a Time-Based Efficiency (TBE) model. The TBE model was developed to evaluate operational performance through Operations Utilization (OU), Operations Efficiency (OE), and Capacity Utilization (CU). During the Define and Measure phases, a production volume deficit of 386 tons (12.7%) was linked to low operational efficiency, with an average OE of 53.2%. Analysis identified technical breakdowns (12.07%), minor stoppages (6.77%), and machine speed losses (4.65%) as the major sources of inefficiency, accounting for 23.49% of total losses. Process capability assessment of the packaging machine revealed poor process stability, with a Cp of 0.63 and Cpk of 0.51. Root cause analysis using Pareto and Fishbone techniques identified equipment deterioration, operator skill gaps, inadequate maintenance practices, spare parts shortages, and process variability as key contributors to performance losses. Improvement actions included machine overhauling, preventive maintenance implementation, operator training, process standardization, employment of a packaging machine specialist, and spare parts management. Following implementation, process capability improved significantly to Cp = 2.06 and Cpk = 2.01, indicating a statistically controlled process. Operational efficiency increased from 53.2% to 77.9%, while capacity utilization improved from 45.3% to 67.8%. Production volume compliance also increased to 95.9% of plan. The findings demonstrate that integrating DMAIC with a Time-Based Efficiency model provides an effective framework for identifying, eliminating, and sustaining reductions in operational losses, thereby enhancing manufacturing productivity and reliability.

Keywords— DMAIC, Lean Six Sigma, Operational Efficiency, Root Cause.

1 INTRODUCTION

A lean approach is a framework for cutting waste or inefficiency. Using people, materials, machinery, and time as efficiently as possible reduces the resources used in production. Waste includes all resources that do not provide value to the consumer. This fosters an approach of constant enhancement, in which companies find and eliminate waste up to the point they achieve optimal performance (Singh, 2025; Maheshwari & Devi, 2024). Lean Six Sigma is a blend of the two methods, "Six Sigma" and "Lean." Whereas Six Sigma focuses on quality control, the Lean technique addresses waste management. This unique approach combines Lean and Six Sigma techniques and is a powerful instrument for streamlining manufacturing operations and boosting profits. Lean Six Sigma methodologies have emerged as pivotal strategies for enhancing efficiency, improving quality, reducing variations, and improving cost-effectiveness within manufacturing operations. Some of the principles of Lean Six Sigma are continuous improvement, focus improvement, variation management, and value mapping. The synergy between Lean production and Six Sigma aims to strengthen and offer a comprehensive approach to process improvement (Ibikunle et al., 2024; Vicente et al., 2024).

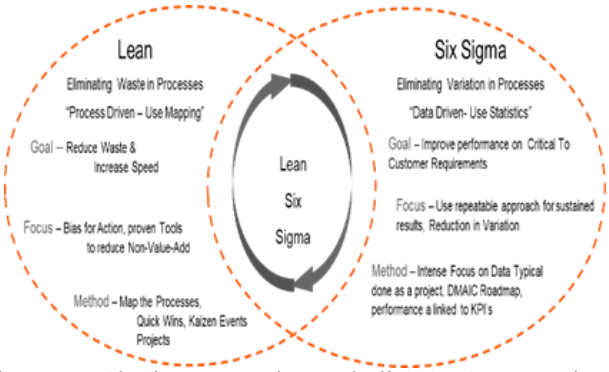

Fig. 1. Lean Six Sigma Venn Diagram (Asif, 2021; Gomaa et al., 2023)

Figure 1 shows the Venn diagram of the synergy between Lean and Six Sigma. It gives goals, focus, and methods applicable to Lean Six Sigma implementations. The implementation strategies of Lean Six Sigma apply to manufacturing and non-manufacturing sectors. It is also applicable to all processes that need to be improved. There are other strategies for process improvement, such as Poka Yoke, SMED, Plan-Do-Check-Act, and Total Productive Maintenance (Husar *et al.*, 2023). Lean Six Sigma is different from every other process improvement methodology due to its ability to be adapted to improve any processes and operations. The two main methodologies used in Lean Six Sigma are DMAIC and DMASC. DMAIC, which stands for define, measure, analyze, improve, and control, is used to improve manufacturing operations. Meanwhile, DMASC, which stands for define, measure, analyze, standardize, and control, is used to standardize manufacturing operations. (Demirtas et al., 2024; Hasanah, 2024; Carrim & Gupta, 2024).

Corresponding Author: olusesanadegoke@yahoo.com
Section C- MECHANICAL/MECHATRONICS ENGINEERING & RELATED SCIENCES
Can be cited as:
Olusesan A.E., Bolaji B.O., Olorunfemi B.J, & Omotosho O.E. (2026), DMAIC Application for Time-Based Operational Efficiency Improvement. FUOYE Journal of Engineering and Technology (FUOYE**JET**), **11(3), 463-471.** https://dx.doi.org/10.46792/fuoyejet.v11i3.1436

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)

Bart et al. (2021) researched to understand the challenges faced in implementing Lean Six Sigma (LSS) for operational excellence in digital emerging technology companies. The study conducts case studies of LSS implementations in six US-based companies in this industry. The findings highlight critical success factors, including engaged organizational leadership, adapting LSS methodology to fit existing values, restructuring training programs, and modifying project execution methods. The research acknowledges limitations in sample size and geographic coverage but offers practical implications for companies focusing on product development, innovation, and growth, particularly in high-tech manufacturing sectors. The study contributes to filling a gap in understanding industry-specific enablers for successful LSS implementation in digital emerging technology companies and providing guidance for practitioners.

Kurnia and Purba (2021) carried out a literature review to examine Lean Six Sigma (LSS) implementation in the manufacturing industry, focusing on the period from 2015 to 2020. They explore the DMAIC (Define, Measure, Analyse, Improve, and Control) approach, widely used in LSS implementations. The review encompasses 50 articles from various databases and publishers, analyzing perspectives such as industry focus, distribution by country, publication year, and publisher count. It offers insights valuable for manufacturing industries seeking problem-solving solutions and suggests avenues for future research to enrich the literature on LSS implementation.

Ramakrishna & Alzoubi (2022) explore the role of Six Sigma and Lean Operations in reducing the Cost of Quality (COQ) in service sector companies in the UAE, particularly those listed in the Dubai Financial Market. It employs empirical research, conducting a field survey with 120 structured questionnaires to gather data. Results indicate the importance of implementing Six Sigma to enhance service quality and reduce quality-related costs. The study suggests creating awareness about Six Sigma, Lean Management, and Total Quality Management concepts and their practical implications, and advocates for adopting professional methodologies to implement these concepts in service companies listed in the Dubai Financial Market.

Abdulrakeeb (2015), examines the implementation of lean Six Sigma (LSS) methodology in small and medium-sized enterprises (SMEs), with a focus on the paper cement bags industry. LSS is increasingly utilized across industries to address quality-related challenges. The research aims to not only study the LSS framework but also emphasize its implementation in SMEs. By applying LSS methodologies, the study seeks to reduce waste and defects and enhance sigma levels. Results from the cement bags industry implementation indicate potential increases in production rate, significant cost savings from waste and defect reduction, and improvements in preparation time and sigma level. Specifically, the study shows a 4.25% increase in production rate and savings of $21,682.61 per year through waste and defect reduction. Additionally, preparation time is reduced by 4.57%, and the sigma level improves from 3.91 to 4.00. Hari and Diesta (2017) discussed the application of Lean Six Sigma (LSS) principles, initially developed in the automotive industry, in manufacturing processes, particularly focusing on a case study involving the improvement of a gas stove production process.

In today's competitive manufacturing landscape, achieving high operational efficiency is essential for sustaining profitability and maintaining market share. The common Operational efficiency model is Overall Equipment Effectiveness (OEE), which provides manufacturers with a structured approach to evaluate equipment and process utilization. By focusing on metrics like availability, performance, and quality within specified time intervals, these models help organizations pinpoint areas for improvement and optimize their resource use. However, implementing these models effectively and sustaining improvements require a robust, data-driven framework for problem-solving. The focus of this work is to apply a time-based model of operational efficiency to drive improvement, which is different from Overall Equipment Effectiveness. The Define-Measure-Analyze-Improve-Control (DMAIC) methodology, a core component of Six Sigma, offers a systematic approach to addressing operational challenges. With its structured phases, DMAIC facilitates detailed analysis of process inefficiencies, supports data-driven decision-making, and ensures that implemented improvements are controlled and maintained over time. In the context of time-based operational efficiency models, DMAIC can enhance performance by providing a clear roadmap to diagnose inefficiencies, identify root causes, and implement sustainable improvements (Kumar & Kumar, 2024; Munyaka et al., 2024)

This study investigates the application of the Define-Measure-Analyze-Improve-Control (DMAIC) framework within a Time-Based Efficiency (TBE) operational efficiency model to improve manufacturing productivity and minimize operational losses. While Lean Six Sigma has been widely adopted as a continuous improvement methodology across manufacturing industries, existing studies predominantly concentrate on Overall Equipment Effectiveness (OEE), quality improvement, defect reduction, and waste elimination. Consequently, limited attention has been given to the use of DMAIC for improving operational efficiency through a comprehensive time-based assessment that captures both planned and unplanned production losses.

The absence of a structured methodology for identifying, quantifying, analyzing, and controlling time-related losses creates a significant gap in manufacturing performance management. As a result, many organizations struggle to accurately diagnose the root

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)

http://dx.doi.org/10.46792/fuoyejet.v11i3.1436 engineering.fuoye.edu.ng/journal

causes of efficiency losses, prioritize improvement initiatives, and sustain performance gains. To address this gap, this study integrates DMAIC with a Time-Based Efficiency (TBE) model that evaluates operational performance through Operations Utilization (OU), Operations Efficiency (OE), and Capacity Utilization (CU).Using a sandwich biscuit packaging line as a case study, the research demonstrates how the DMAIC framework can systematically identify major loss contributors, evaluate process capability, perform root cause analysis, implement targeted improvement actions, and establish effective control measures for sustainable performance improvement. The study highlights measurable improvements in downtime reduction, process stability, equipment reliability, operational efficiency, and production volume compliance.

2. MATERIALS AND METHOD

2.1 Lean Six Sigma Modelling

Lean Six Sigma model is being developed using the DMAIC strategy, which stands for Define, Measure, Analyse, Improve, and Control, to improve operational efficiency.

1. Define phase

The define phase outlines the problem's definition and scope, chooses the project's key metrics and team, and drafts the project charter. The project charter, problem/opportunity statement, objective, primary/secondary metrics, problem-solving team selection, and project timetable are the topics that will be addressed during this phase. The defined phase actions are detailed in Table 1 below. The goal is to increase the sandwich biscuit packaging machine's operational efficiency. The strategy involves determining which elements need improvement and applying Lean Six Sigma techniques.

Table 1. Define Phase Activities

SN	Description
1	The system to improve has been identified according to business priorities
2	Main losses and sources have been identified
3	Value-add steps have been defined
4	Potential critical process parameters that affect attributes have been identified

2. Measure phase

To measure the current state of the process or operations and make improvements, this phase uses statistical concepts and methods. Process mapping, fundamental statistical ideas, graphical tools, measurement system analysis, etc. are some of the instruments utilized. Table 2 provides information on the factors considered throughout the measurement phase and the instruments employed for the Key Performance Indicator for gathering data.

Table 2. Measurement Phase Activities

SN	Description
1	All measurement system analyses (MSAs) are validated under regular conditions
2	Performance losses have been calculated against the target run rate.
3	Establish baseline metrics for each KPI,

3. Analysed phase

This stage provides a thorough root cause investigation of the issue or circumstance identified during the measure phase. Failure Modes and Effects Analysis (FMEA), Hypothesis Testing, Multi-Vari Analysis, Correlation/Regression, simple regression, multiple regression, and fishbone diagram are among the tools utilized. Fishbone (Ishikawa) diagrams are used in the Root Cause Analysis to find possible reasons for inefficiency. The four focus areas at the analysis phase are.

1. Analysis of the top three unplanned efficiency losses compared to the target.
2. Process capability of the machine that contributed to these losses.
3. Pareto chart of all the technical failures.
4. Root cause analysis of the focus machines using Fishbone analysis.

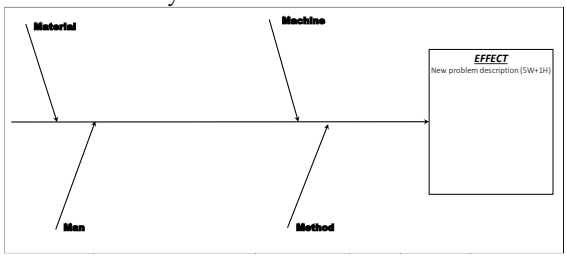

Fig. 2. Fishbone Analysis

The process capability (Cp) ratio is calculated using the following formula:

$$\text{Process capability} \quad \text{Cp} = \frac{(\text{USL}-\text{LSL})}{6\sigma}$$

$$\text{Upper process capability} \quad \text{Cpu} = \frac{(\text{USL}-\bar{x})}{3\sigma}$$

$$\text{Lower process capability} \quad \text{Cpl} = \frac{(\bar{x}-\text{LSL})}{6\sigma}$$

$$\text{Process capability index} \quad \text{Cpk} = \min(\text{Cpu}, \text{Cpl})$$

Where, USL = The upper specification limit

LSL = The lower specification limit

$\bar{x}$ = Mean

σ = sigma = The standard deviation

4. Improve phase.

The issues identified during the analysis phase are often resolved and improved during this phase. The design of experiments (DOE) is the main tool utilized. During this phase, action plans are created to address the underlying causes of inefficiency, lean tools are put into practice, and Six Sigma approaches are applied to increase process capability and minimize variance. A controlled pilot test of the suggested changes will be carried out, data will be gathered to assess the improvements' efficacy, and improvement tactics will be adjusted and improved in response to the pilot test results. The implementation of the complete production process with staff training and development will be the effective enhancements.

5. Control phase

In order to make sure that issues are resolved and gains are sustainable, this phase uses statistical process control (control charts) and control plans. Details of the

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)

http://dx.doi.org/10.46792/fuoyejet.v11i3.1436 engineering.fuoye.edu.ng/journal

considerations made during the control phase are provided in Table 3 below.

Table 3. Control Phase Activities

SN	Description
1	Control plan including control points, sample size, frequency, reaction plan
2	Control charts have been installed to monitor variation of main attributes
3	All process parameters are within defined specifications
4	Control charts of attributes reflect the process is under statistical control.
5	A system to identify special causes of variation has been implemented
6	All documents have been updated (visual aids, detailed process sheets, etc.)

2.2 Time-Based Efficiency Modelling

The model developed for production performance tracking is time-based to measure efficiency. This will make it universally acceptable to track any machine's performance. 100% Time-Based Efficiency (TBE) means the line was running all the time it was used (100% availability rate) at its maximum speed (100% performance rate) and produced only good/saleable products (100% quality rate). Any downtime or loss of efficiency, planned or unplanned, running below maximum speed, or producing defective products will reduce TBE %. Table 4 gives the descriptions of the components used in the model

Table 4. Descriptions of the model components

Components	Descriptions
Calendar Time	This is all time available during the full year. = 24 hrs x 365 days = 8760 hrs.
Legal non-operating time	This is the time that the factory is not allowed to operate due to governmental regulations and union contracts.
No demand	The line was idle due to lack of market demand
Force Majeure	Line production stops due to special reasons such as natural disasters, Attacks, etc.
Autonomous Maintenance	Planned time to perform autonomous maintenance activities.
Planned Maintenance	Planned time to perform maintenance activities.
Sanitation	Planned time to clean the machine to accomplish the quality requirements.
Change over	The total time to change from one Stock Keeping Unit (SKU) to another.
Planned Stops	Planned time to perform specific activities as scheduled in the production plan.
Consumable Replacement	Line stops to replace consumables.
Start-Up & Shutdown	Total time to perform all activities to start and finish the production.
Labor Losses	Unplanned stops due to labour-management issues.
Material Shortages	Unplanned stops because materials needed are unavailable.
Minor stops	Any Unplanned Stops < 10 minutes without a reason recorded.
Technical Breakdown	Unplanned stops with the need to replace or repair the equipment components.
Operational Losses	Unplanned stop of the machine with a reason without the need to replace or repair any component(s). Or Unplanned stops with unknown reason >= 10 Min.
Line Delays	Unplanned stop of the machine on which OE is measured due to a stop of the upstream or downstream processes.
Machine Speed Loss	Equivalent time that the Line is running below the Engineered Design speed of the bottleneck equipment
Quality Loss	Equivalent time that the line is run to produce a product that fails to meet quality standards.

Below is the step by step follow to build this model.

Step 1: **Utilization Hours** = Calendar Time – Legal Non-Operating Time – No Demand – Force Majeure

Step 2: **Production Hour** = Hours Used – Planned maintenance – Autonomous maintenance – Sanitation – Changeovers – Planned stops – Consumables replacement – Start-up and shutdown

Step 3: **Operating Time** = Production Hour – Labor Management Losses – Material Shortages – Minor Stoppages – Breakdowns – Operational Losses – Line Delays – Speed Loss – Quality Loss

Step 4: **Operations Utilization (OU):** This is a measure to show the extent to which the line is utilized. Operations Utilization is calculated by dividing the utilization hour (hours legally available for the line to do any activity, expressed in hours) by the maximum calendar time (also expressed in hours) in the same considered period.

$$OU\ \% = \frac{\sum \textbf{Utilization Hours (hours)}}{\sum \textbf{Maximum Calendar Time (hours)}}$$

Step 5:**Operations Efficiency (OE):** This is a measure to show the extent to which a machine can perform optimally without any problem. Equipment Efficiency is calculated by dividing the operating time (expressed in hours) by the utilization hour (also expressed in hours) in the same considered period.

$$OE\ \% = \frac{\sum \textbf{Operating time (hours)}}{\sum \textbf{Utilization Hours (hours)}}$$

Step 6: **Capacity Utilization (CU):** This measure shows the extent to which production capacity is utilized. Capacity Utilization is calculated by dividing the operating hour (actual production, expressed in hours) by the maximum calendar time (also expressed in hours) in the same considered period.

$$CU\ \% = \frac{\sum \text{Operating time (hours)}}{\sum \text{Maximum Calender Time (hours)}}$$

3 RESULT AND DISCUSSION

The case study is a sandwich biscuit packaging machine. The results achieved, based on the methodology applied, are below.

1. Define Phase

As shown in Figure 3. There is a consistent drop in production volume due to the continued operational efficiency issues, as shown in Figure 4. This miss in volume is directly related to the miss in operational efficiency.

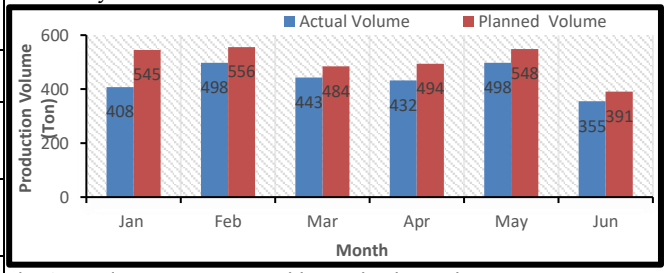

Fig. 3. Pre-improvement Monthly Production Volume

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)

http://dx.doi.org/10.46792/fuoyejet.v11i3.1436 engineering.fuoye.edu.ng/journal

B. Measures Phase

The volume miss was 386 tons (12.7 %) of the planned production volume. Operational Efficiency is the determining factor of production volume.

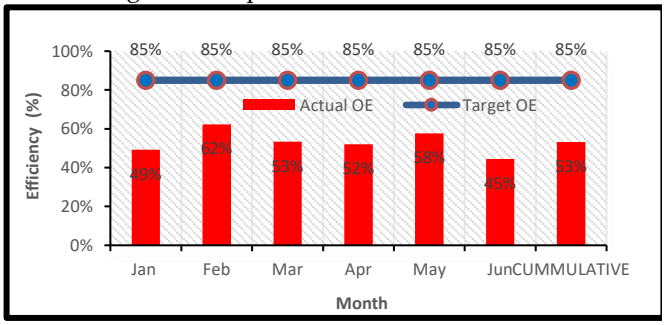

Fig. 4. Pre-improvement Monthly Operational Efficiency

Figure 4 above shows the month-on-month trend of the pre-improvement monthly Operational Efficiency. This shows that operational efficiency has been trending below target. Table 5 shows the six-month cumulative of the pre-improvement efficiency outlook.

Table 5. Pre-Improvement Efficiency Outlook

Time Loss	Operational Efficiency Component	Six Months Cumulative	
		Hrs	%
Calendar Time		4368	4368
Shutdown	Legal non-operating time	648	15%
	No demand	0	0%
	Force Majeure	0	0%
Utilization Hours		3720.00	85%
Planned Losses	Autonomous Maintenance	0	0%
	Planned Maintenance	432	12%
	Sanitation	99	3%
	Change over	0	0%
	Planned Stops	102	3%
	Consumable Replacement	115	3%
	Start-Up & Shutdown	0	0%
Production Hour		2972.00	80%
Unplanned Losses	Labor Losses	0	0%
	Material Shortages	0	0.00%
	Minor stops	252	6.77%
	Technical Breakdown	449	12.07%
	Operational Losses	57	1.53%
	Line Delays	0	0.00%
	Machine Speed Loss	173	4.65%
	Quality Loss	61	1.64%
Operating Time		1980.00	53%
Productivity	OU	85%	
	OE	53.2%	
	CU	45.3%	

C. Analyse Phase

The plant efficiency losses impacted production volume. The plant's Operational Efficiency (OE) achieved 53.2% cumulatively in six months. The total efficiency loss is 47% (27% were unplanned and 20% were planned losses). The root cause analysis focused on how to reduce unplanned losses. And the flowing steps were adopted.

1. Analysis of the three top unplanned efficiency losses compared to the target.
2. Process capability of machines that contributed to these losses.
3. Pareto chart of all the technical failures.
4. Root causes analysis of the focus machines using Fishbone analysis.

1. Three top unplanned efficiency losses.

The three top unplanned efficiency losses are technical breakdown (12.07% losses), Minor Stops (6.77% Losses), and speed loss (4.65% losses). The three losses contributed 23.49% of 27% of total unplanned loss. Every other unplanned loss accumulated to be 3.17%.

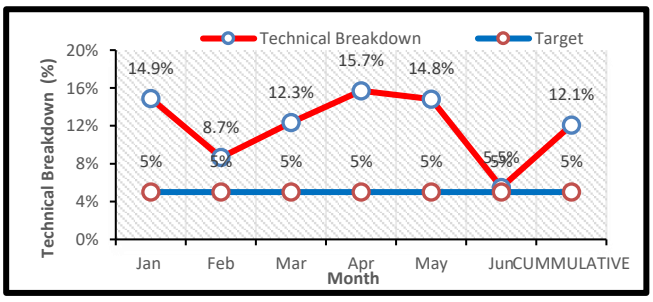

Fig. 5. Technical Breakdown

Figure 5. shows the month-on-month technical breakdown trend. The worst month is April (15.7%), followed by January (14.9) and May (14.8%) breakdown losses. March was 12.3% and February was 8.7%. June was close to the target which is 5.5%. The cumulative technical breakdown loss is 12.1% in six months.

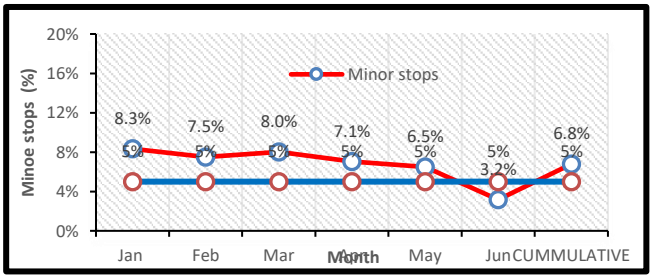

Fig. 6. Minor Stops

Figure 6 shows the month-on-month minor stop trend. The worst month is January with 8.3% losses, followed by March (8.0%), then February (7.5%), April (7.1%), and May (6.5%), and June data is within the control and the best with 3.2%. The cumulative loss is 6.8% in six months.

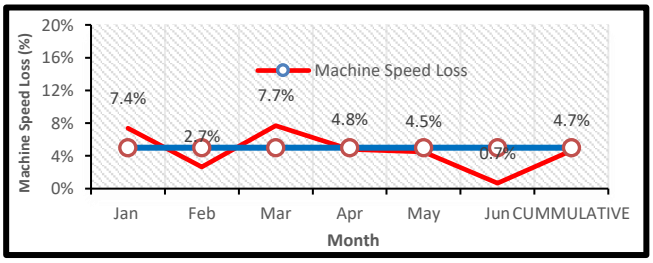

Fig. 7. Machine Speed loss

Figure 7 shows the month-on-month machine speed loss trend. There are just two months that are above target: January (7.4%) and March (7.7%). The cumulative loss is 4.7% in six months, and this is far better than the target.

2. Process capability of the packing machine.

The processing capability of the packing machine was tracked to determine the level of deviations from the set parameter before improvement. The main parameter for the packing machine is the laminate cut-off length. 49 samples were taken because there are 49 product pieces in a carton of 28g products.

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)

http://dx.doi.org/10.46792/fuoyejet.v11i3.1436 engineering.fuoye.edu.ng/journal

Table 6. Packing Machine Processing Capability (Pre-Improvement)

Packing Machine Processing Capability					
Packaging Materials Cut-Off Length Specification (mm)		Nominal	34	-0.2	+0.2
		Min	33.8	Max	34.2
Std Deviation (s)	0.105	Sample Size			49
Mean (m)	33.962	Short Term Capability (Cp)			0.63
Upper Control Limit (UCL)	34.277	Short Term Centered Capability (Cpk)			0.51
Lower Control Limit (LCL)	33.646	Lower Standard Limit (LSL)			33.80
Standard	34.00	Upper Standard Limit (USL)			34.20

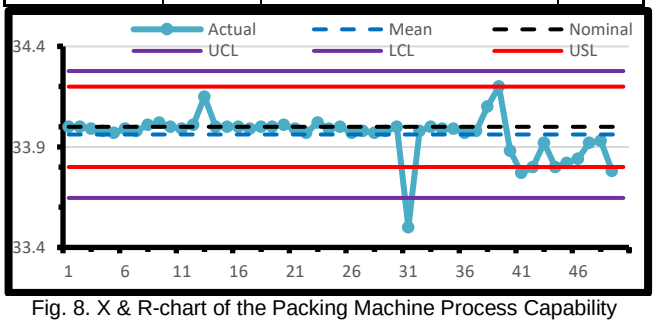

Fig. 8. X & R-chart of the Packing Machine Process Capability

The nominal Packaging Materials Cut-Off Length is 34 ± 0.2 mm. The standard deviation is 0.105, and the Centred Capability (Cpk) is 0.51. The lower value of Centred Capability (Cpk) of less than 2 shows that this system is out of control. Figure 8 above shows the X-chart and R-chart of the packing machine process capability. Figure 9, shows the level of non–compliance of the Packing Machine to Packaging Materials Cut-Off Length

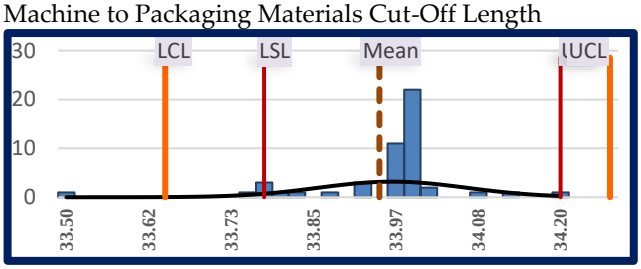

Figure 9. Packing Machine Process Capability – Packaging Materials Cut-Off Length

From the above chart (Figure 9), the overall standard deviation is 0.105. This shows that the process capability variation has a wider margin and is out of control.

3. Pareto chart of all the technical failures.

The packing machine-related technical issues were further investigated using a Pareto chart as shown below.

Fig. 10. Pareto chart of the technical failures. – Packing Machine Contributions

There are six packing machines on this line; Figure 10 shows the Pareto chart of the technical failures. Based on each packing machine's contributions. Packing Machines 4 and 5 contributed a 68.9% failure rate. Machine 4 had the highest failure rate at 35.5%, while packing machine 5 contributed a 33.4% failure rate. Other packing four machines combined contributed 31.1%. A further Pareto chart was done on the main technical failures as shown below.

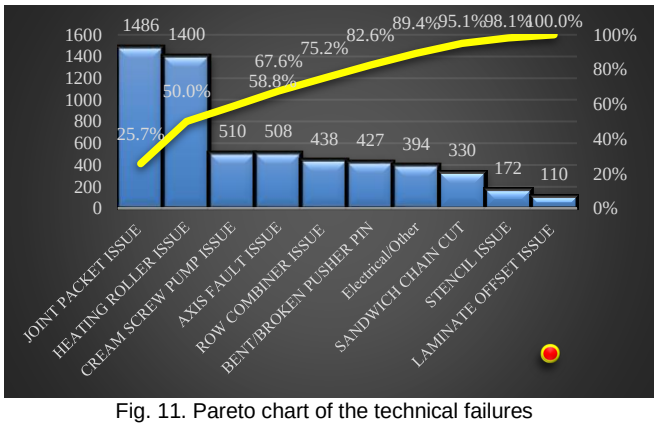

Fig. 11. Pareto chart of the technical failures

From Figure 11, Joint Packet and Heating Roller issues contributed 50% of the problem. The other eight problems contributed 50%. The contribution of each problem to the total technical failure are row combiner issue (8%), bent/broken pusher pin (7%), sandwich chain cut (6%), joint packet issue (26%), heating roller issue(24%), laminate offset issue (2%), cream screw pump issue (9%), stencil issue (3%), axis fault issue (9%), and electrical/other (7%).

Table 7. Technical failures - Cause

SN	Issue	Causes
1	Row Combiner Issue	Misalignment due to mechanical wear
2	Bent/Broken Pusher Pin	improper installation
3	Sandwich Chain Cut	Material fatigue due to improper tension
4	Joint Packet Issue	Poor sealing and incorrect size
5	Heating Roller Issue	Temperature inconsistency and roller damage
6	Laminate Offset Issue	Misalignment during feeding
7	Cream Screw Pump Issue	Clogging, wear and tear
8	Stencil Issue	Misalignment due to wear and tear
9	Axis Fault Issue	Sensor failure & mechanical obstruction
10	Electrical/Other	Short circuits & component failure

4. Root Causes Analysis

Below is the result from the Fishbone analysis with 4M (Man, Machine, Materials, and Methods)

Table 8. Explanation of the Root Cause Analysis – Tempering Machine

Source	Issues	Explanations
Man	Operator skills gap	Most of the operators lack machine operations expertise. Due to the high attrition of trained operators
	No packing machine specialist	There is no dedicated packing machine specialist. All technicians are working across the plant.
Method	Frequent changes in Biscuit sizes	To ensure a positive Gross Profit, price pack adjustments are frequently implemented. The smaller the size, the more difficult the settings & operations
	Maintenance	Scheduled preventive maintenance is not followed. Condition & Staggered maintenance was adopted.

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)

http://dx.doi.org/10.46792/fuoyejet.v11i3.1436 engineering.fuoye.edu.ng/journal

Materia l	Cream flipping on biscuit shell	Due to the minimum cream dispenser capability being higher than the current requirement for the 28g SKU
	Non-availability of spare parts	Non-availability of spare parts makes abnormality closure difficult. Most of the spares are imported.
Machine	Machines not in the base condition	High level of wear and tear on machine components, cum non-functioning of the defective rejection system of the packing machines.

D. Improve Stage

Based on the gap analysis done above. Below are the major improvements implemented.

Table 9. Improvement Actions – Packing Machine

SN	Issue	Solution
1	Row Combiner Issue	Realign components and replace worn parts
2	Bent/Broken Pusher Pin	Replace the pin, reduce load, and ensure proper fit
3	Sandwich Chain Cut	Replace the chain and adjust the tension
4	Joint Packet Issue	Adjust sealing parameters and verify packet size
5	Heating Roller Issue	Repair/replace rollers and check heating elements
6	Laminate Offset Issue	Realign the laminate feed and check the sensors
7	Cream Screw Pump Issue	Clean the pump & replace parts as needed
8	Stencil Issue	Replace stencils and realign the application mechanism
9	Axis Fault Issue	Check sensors and clear obstructions
10	Electrical/Other	Inspect wiring and replace faulty components

Table 10. Improvement Actions – General Root Cause

Issues	Action
Operator skills gap	Develop operators' capability in machine operations through training
No packing machine specialist	Get a Packing Machine Specialist
Frequent changes in Biscuit sizes	Standardisation and definition of optimal configurations for capability.
Maintenance	Implement a time and volume-driven preventive maintenance
Cream flipping on biscuit shell	Get a new cream dispenser with the correct capability from the OEM
Non-availability of spare parts	Create a list of critical spares and make an order once it reaches the reorder point.
Machines not in the base condition	Carried out a complete overhaul.

Table 11 gives the improved packing Machine Processing Capability

Table 11. Improved Packing Machine Processing Capability

Packing Machine Processing Capability					
Packaging Materials Cut-Off Length Specification (mm)		Nominal	34	-0.2	+0.20
		Min	33.80	Max	34.20
Std Deviation (s)	0.032	Sample Size			49
Mean (m)	34.005	Short Term Capability (Cp)			2.06
Upper Control Limit (UCL)	34.102	Short-Term Centred Capability (Cpk)			2.01
Lower Control Limit (LCL)	33.908	Lower Standard Limit (LSL)			33.80
Standard	34.00	Upper Standard Limit (LSL)			34.20

Figure 12 below shows the X-chart and R-chart of the packing machine process capability.

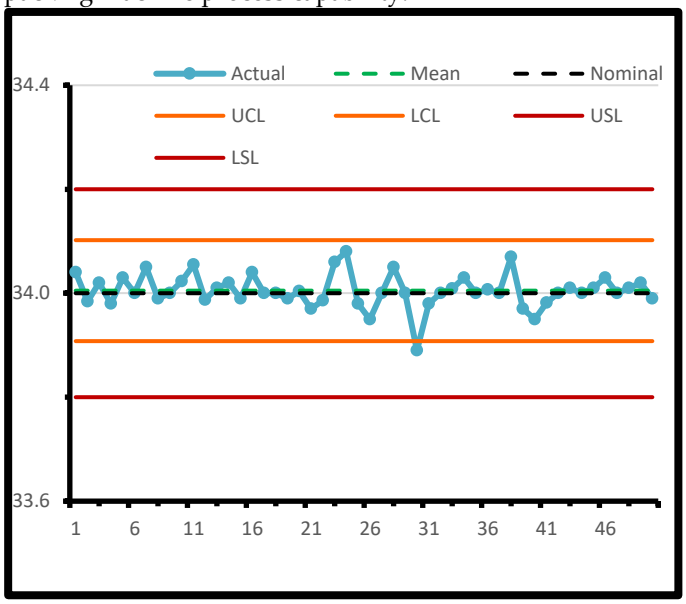

Fig. 12. X & R-chart of the Packing Machine Process Capability (Post-improvement)

Figure 12 shows the level of compliance level of the Packing Machine. The cut-off length is within control and the mean value of the set standard. 49 readings were taken again at different times to understand the cut-off length variability of the packing machine after the improvement. The actual cut-off length falls within the range of 33.8 mm and 34.2 mm. The standard deviation also reduced to 0.032 from an initial value of 0.105, and the Centred Capability (Cpk) improved in stability to 2.01. The positive value above 2 shows that this system is now under control.

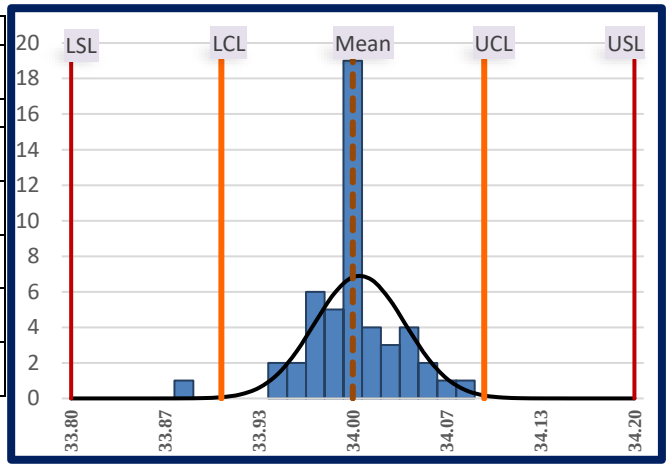

Fig. 13. Post-improvement process capability

From the above chart (Figure 13), the mean value is 34.005, while other parameters are within the lower and upper control limits. Also, Production performance (volume) is stabilized and can be predicted due to the improvement process. This meant that the equipment had been brought back to base condition. Figure 14 shows the volume compliance of the post-improvement implementations. The post-implementation cumulative deliverable production volume is 95.9% compliant with

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)

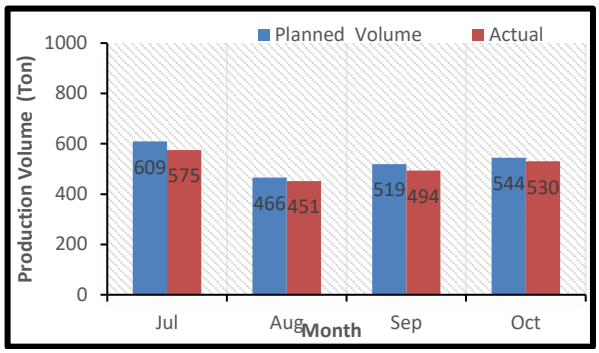

Fig. 14. Post-Implementation volume compliance

the plan, which is a great improvement compared to the first six months. Table 12, given the post-implementation time-based efficiency of the case study, the Operations efficiency is 77.9% cumulative, which is 24.7% better than the pre-improvement efficiency outlook (Table 5) of 53.2% cumulative.

Table 12. Post-Implementation Time Base Efficiency.

Time Loss	Operational Efficiency	Four Months Cumulative	
		Hrs	%
Calendar Time		2952	
Shutdown	384	13%	15%
	0	0%	0%
	0	0%	0%
Utilization Hours		2568.00	87%
Planned Losses	0	0%	0%
	90	4%	12%
	51	2%	3%
	0	0%	0%
	51	2%	3%
	47	2%	3%
	0	0%	0%
Production Hour		2329.00	91%
Unplanned Losses	0	0%	0%
	0	0.00%	0.00%
	81	3.15%	6.77%
	129	5.02%	12.07%
	32	1.25%	1.53%
	0	0.00%	0.00%
	58	2.26%	4.65%
	28	1.09%	1.64%
Operating Time		2001.00	78%
Productivity	**OU**	**87%**	
	OE	77.9%	
	CU	**67.8%**	

Figure 15 shows the month-on-month trend of pre- and post-improvement operational efficiency and capacity

Fig. 15. Pre- and Post-Improvement Operational Efficiency

utilization. Before improvement, the plant capacity delivered an average operational efficiency of 53.2% and capacity utilization of 45.3%. Post-improvement operational efficiency is 77.9% on average and capacity utilization is 67.8%.

E. Control Phase.

The controls are in place below for the gaps discovered using Root Cause Analysis (Fishbone analysis with 4M).

Table 13. Control Measure – Packing Machine

SN	Issue	Control
1	Row Combiner Issue	Regular maintenance checks and alignment procedures
2	Bent/Broken Pusher Pin	Load limits and routine inspections
3	Sandwich Chain Cut	Regular tension checks and quality materials
4	Joint Packet Issue	Calibration checks and periodic size verification
5	Heating Roller Issue	Temperature monitoring & routine inspections
6	Laminate Offset Issue	Alignment checks and sensor calibration
7	Cream Screw Pump Issue	Regular cleaning schedule and wear monitoring
8	Stencil Issue	Inspection schedule and proper handling procedures
9	Axis Fault Issue	Sensor calibration and regular operational checks
10	Electrical/Other	Regular electrical inspections and fault detection systems

Table 14. Control Measure – Issues

Issues	Control
Operator skills gap	OEM training became part of the induction training for the new operators.
No packing machine specialist	A new packing machine specialist was employed
Frequent changes in Biscuit sizes	All new product development must be cycled
Maintenance	Planned Preventive Maintenance incorporated into a production planning meeting
Cream flipping on biscuit shell	New dispenser with spare procured and fixed
Non-availability of spare parts	Reorder level standardize
Machines not in the base condition	Implement a time-based maintenance plan on the packing machine.

4 CONCLUSION

This study successfully demonstrated the application of the Lean Six Sigma Define-Measure-Analyze-Improve-Control (DMAIC) methodology for improving manufacturing performance using a Time-Based Efficiency (TBE) operational efficiency model. Unlike conventional improvement approaches that primarily focus on Overall Equipment Effectiveness (OEE), the proposed TBE framework provided a comprehensive method for identifying, quantifying, and managing both planned and unplanned time losses that directly affect

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)

http://dx.doi.org/10.46792/fuoyejet.v11i3.1436 engineering.fuoye.edu.ng/journal

operational efficiency, capacity utilization, and production output.

The Define phase established the relationship between declining production volume and poor operational efficiency. During the Measure phase, baseline performance data revealed that operational efficiency averaged 53.2%, resulting in a production shortfall of 386 tonnes, equivalent to 12.7% of planned output. The Analyze phase identified technical breakdowns, minor stoppages, and machine speed losses as the dominant contributors to inefficiency. Further investigation through process capability analysis, Pareto analysis, and Fishbone root cause analysis revealed deficiencies related to machine condition, maintenance practices, operator competence, spare parts availability, and process variability.

Targeted corrective actions implemented during the Improve phase included machine restoration to base conditions, preventive maintenance optimization, operator capability development, process standardization, improved spare parts management, and the engagement of a packaging machine specialist. These interventions significantly improved process stability, increasing the packaging machine capability from a Cp of 0.63 and Cpk of 0.51 to a Cp of 2.06 and Cpk of 2.01. Operational efficiency improved from 53.2% to 77.9%, representing a 24.7 percentage-point increase, while capacity utilization increased from 45.3% to 67.8%. Furthermore, production volume compliance improved to 95.9% of the production plan, demonstrating the effectiveness of the implemented solutions.

The Control phase established sustainable mechanisms, including preventive maintenance schedules, operator training systems, process monitoring controls, spare parts management procedures, and equipment performance reviews, to prevent performance deterioration and ensure continuous improvement.

The findings confirm that integrating DMAIC with a Time-Based Efficiency model provides a practical, data-driven, and sustainable framework for operational efficiency improvement in manufacturing environments. The study contributes to the existing body of knowledge by extending Lean Six Sigma applications beyond traditional OEE-based assessments and introducing a structured methodology for managing time-related losses and improving production reliability. It is therefore recommended that manufacturing organizations adopt a time-based operational efficiency approach as a complementary performance management tool and ensure that critical operational challenges are clearly defined before embarking on Lean Six Sigma improvement initiatives.

REFERENCES

Abdulrakeeb, A.G., Mahmoud, A.E., and El-Sebaie, M.G. (2015). An Application of Lean Six Sigma (LSS) in Small and Medium Enterprises (SMEs): Cement bags industry. International Journal of Scientific & Engineering Research, 6(5), 430-436.

Asif, M. (2021). Lean Six Sigma institutionalization and knowledge creation: towards developing theory. *Total Quality Management & Business Excellence*, 32(7-8), 811-828. https://doi.org/10.1080/14783363.2019.1640598.

Bart, L. A., Wilmer, P., & Jiju, A. (2021). The implementation of Lean Six Sigma for operational excellence in digital emerging technology companies. Journal of Manufacturing Technology Management, 32(9), 260-284. doi:10.1108/JMTM-09-2020-0373

Carrim, M. O., & Gupta, K. (2024). Improving Efficiency and Productivity of a Production Line Using Lean Manufacturing and DMAIC. Link: https://irjstem.com/wp-content/uploads/2024/11/IRJSTEM-V4N3-2024-P01.pdf [irjstem.com]

Demirtas, E.A., Kostur, G.Y. and Kara, M.E. (2024). DMAIC Cycle for the New Product Launch Process: FMEA and DOE Applications for Built-In Oven. *Verimlilik Dergisi*, 58(1), 29-44.

Gomaa, A.H. (2023). A systematic review of Lean Six Sigma in manufacturing domain. *Engineering Research Journal*, 52(4), 139-148.

Hari, S., and Diesta., I. M. (2017). A Lean Six-Sigma Manufacturing Process Case Study. *International Journal of Mechanical Engineering and Technology*, 8(7), pp. 498–509. http://iaeme.com/Home/issue/IJMET?Volume=8&Issue=7

Hasanah, R. (2024). Improving quality through the Lean Six Sigma approach. *Proceeding of International Conference on Education, Society and Humanity*, 2(1), 1019-1037.

Husar, J., Hrehova, S., Trojanowski, P., Wojciechowski, S. and Kolos, V. (2023). Perspectives of Lean Management Using the Poka Yoke Method. In *Design, Simulation, Manufacturing: The Innovation Exchange*, Springer Nature Switzerland, 121-131. https://doi.org/10.1007/978-3-031-32767-4_12.

Ibikunle, A.K., Rajemi, M.F. and Zahari, F.M. (2024). Implementation of lean manufacturing practices and six-sigma among Malaysian manufacturing SMEs: intention to implement IR 4.0 technologies. *International Journal of Quality & Reliability Management*, 41(2), 447-468. https://doi.org/10.1108/IJQRM-03-2022-0086.

Kumar, N., & Kumar, R. (2024). Enhance Operational Efficiency of Manufacturing Process Using Six Sigma in Small Scale Manufacturing Industry: DMAIC Approach. Link: https://ijasce.org/index.php/IJASCE/article/view/192 [ijasce.org]

Kurnia, H., & Purba, H. H. (2021). A Systematic Literature Review of Lean Six Sigma in Various Industries. Journal of Engineering and Management In Industrial Systems, 9(2), 1-12. doi:10.21776/ub.jemis.2021.009.002.3

Maheshwari, P. and Devi, Y. (2024). Investigating the relationship between Lean Six Sigma performance strategy with digital twin modelling: Practices and factors. *Journal of Cleaner Production*, 436, 140449. https://doi.org/10.1016/j.jclepro.2023.140449.

Munyaka, J. C. B., Chenal, J., & Kanyinda, K. (2024). Optimizing Manufacturing Efficiency: A Six-Sigma DMAIC Approach to Reduce Operational Gaps. Link: https://ijiset.com/vol11/v11s1/IJISET_V11_I01_08.pdf [ijiset.com]

Ramakrishna, Y., & Alzoubi, H. M. (2022). Empirical Investigation of Mediating Role of Six Sigma Approach in Rationalizing the COQ in Service Organizations. Operations and Supply Chain Management, 15(1), 122-135.

Singh, S. (2025). Impact of Six Sigma Methodology on Operational Efficiency. Link: https://ijnrefm.com/wp-content/uploads/ijcrst-volume2-issue6-134.pdf [ijnrefm.com]

Vicente, I., Godina, R. and Gabriel, A.T. (2024). Applications and future perspectives of integrating Lean Six Sigma and Ergonomics. *Safety Science*, 172, 106418. https://doi.org/10.1016/j.ssci.2024.106418.

© 2026 Olusesan et al. Published by Faculty of Engineering, Federal University Oye-Ekiti.
This is an open access article under the CC BY NC license. (https://creativecommons.org/licenses/by-nc/4.0/)