

Enhancing Rice Milling Efficiency through Lean-Based Process Improvement Using Value Stream Mapping



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ABSTRACT: Variability within a synchronous flow line due to process inefficiency and waste generation may jeopardise the production throughput. The study seeks to use a lean-based improvement process to enhance an existing rice processing and milling facility in Otukpo, Benue state, Nigeria, using a simulated model of Value Stream Mapping (VSM). The study objective is to appraise the state of the operations at various points in the manufacturing value chain using the existing state value stream map (ESVSM) and seek improvement where there are inefficiencies. The IGrafx software was employed in formulating and modelling the ESVSM, showing the process steps and identifying areas of waste on the processing line. Line balancing charts are drawn through simulation to identify imbalances in the process flow to optimise workflow at various workstations and increase process efficiency. Further analyses were conducted using the Monte Carlo sensitivity analysis with the aid of Python programs to analyse the relationship between metrics such as productivity, quality, cost, and on-time delivery vis-à-vis other metrics such as cycle time, lead time, inventory, work-in-progress, finished goods, value-added time, production efficiency, defect rate, and on-time delivery. The results of the new state value stream map (NSVSM) present a reduction in the following areas: lead time by 61.24%, cycle time by 41.14%, raw material movement time by 64.44% and non-value-added time by 90.08% with improvements in work in progress by 60.04% and overall process efficiency by 28.68% following the implementation of the lean tool. In addition, the simulation results show potential improvement in the overall production efficiency by 73.2%. This study may assist process industry in achieving process improvement. The novelty of this study lies in the fact that the development of a lean-based process for process improvement in rice milling operation using value stream mapping and simulation approach has not been sufficiently reported by the existing literature.

KEYWORDS: Lean tools, Manufacturing value chain, Value Stream Mapping, Wastes

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I. INTRODUCTION

The traditional methods of rice post-harvest processes often fall short of expectations in production capacity, quality of products, and on-time delivery to market. Therefore, meeting customer's demand in this competitive market has become a challenge due to some inherent process variability. In order to meet the increasing product demand, there is a need to improve on the existing method of rice processing and milling methods. This study investigates a rice processing and milling facility at Otukpo, Benue state, where high cycle and lead time as well as high inventory rates and down times are experienced. The paper aims to address these inefficiencies in the rice milling process at Otukpo using the lean manufacturing principle. Lean manufacturing has its focuses on identifying and eliminating manufacturing "waste" in any process, allowing for a free flow process devoid of any obstruction (Oko & Kang, 2015). When

the lean tool is applied holistically, it can streamline and transform processing lines to a more viable, efficient and effective lines for the organisation's economic advantage (Ciarniene & Vienažindiene, 2014; Bhasin, 2015). Lean has been applied in various organisations, both in the manufacturing and the service sectors. Starting with the Toyota in Japan (Ohno, 1988; Ciarniene & Vienažindiene, 2014) by Ohno, lean has evolved through the years to its present status as one of the leading manufacturing and managerial principles. It has been embraced by several manufacturing and processing firms all over the world. Kafuku (2019) as well as Holweg (2007) underscore the importance of lean thinking in improving process transparency and responsiveness, particularly in industries with complex supply chains, such as rice milling. Similarly, Olu-Lawal *et al.* (2024) and Oladipupo *et al.* (2023) expand on this by identifying the seven types of waste that lean manufacturing seeks to eliminate. These are:

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overproduction, waiting, transport, over-processing, inventory, motion, and defects.

Rice milling and processing are integral to the agricultural value chain, especially in rice-producing regions in Nigeria such as Otukpo, Benue State. Despite its significance, the industry is fraught with inefficiencies, including prolonged processing times, excessive inventory, poor quality control, and inconsistent on-time delivery, resulting in high levels of waste. These inefficiencies compromise productivity and profitability, thus highlighting the need for systematic process optimization. Nwanya and Oko (2019) suggest that adopting lean manufacturing principles can address these challenges by streamlining operations and optimising resource utilisation to attain the desired objectives.

The case in this study is a 50-metric-ton rice milling facility in Otukpo, Benue State, Nigeria which provides a compelling opportunity to apply lean manufacturing principles. The industry is currently faced with the challenges of high manufacturing lead time and increase in non-value-added time resulting in overall process cycle efficiency of 65.5% which is lower than the process cycle efficiency of 85% targeted by the management. These challenges suggest the process inefficiency and waste generation in some of the activities at the facility thus, necessitating the use of the lean tool especially the value stream mapping to map out the processes and identify the areas of inefficiencies and waste generation where improvements are needed. With baseline performance metrics showing high lead times, low production efficiency, and excessive inventory, the facility mirrors the challenges identified by Nwanya and Oko (2019) in the broader industries in Nigeria, such as the continuous process industries. The lean concept has been applied in various industries and organisations, starting with the auto-industries, Toyota to be precise, before spreading to other industries like the health sectors, the hospitality industries, and later to the public administration, amongst others (Panwar *et al.*, 2017). However, only a few mentions have been made of lean practice and manufacturing in the continuous process industries, such as the rice processing and milling industry which is the focal point of this study. Existing studies have also not sufficiently considered using Value Stream Map (VSM) in rice milling activities, especially in Nigeria. The same view was shared by Lyons *et al.* (2013) and Abdulmalek and Rajgopal (2007) who stated that lean adoption seems to be lagging in the continuous process industries. Though works have been carried out in continuous process industries like food processing, pharmaceuticals, beverages and petrochemicals (King, 2009), there still exists a gap in the application of the use of lean principles in rice processing and milling. Therefore, the need for this research study to close up this knowledge gap. The study also aims to apply the Monte Carlo method sensitivity analysis in analysing the correlation between input parameters and identifying the variability in the rice processing line. By adopting lean tools such as VSM (Díaz-Reza *et al.*, 2022; Daniyan *et al.*, 2022), the facility can systematically address the inefficiencies, reduce waste, improve productivity, and meet customer's need as at when due.

The study has the objectives of creating value for customers by applying these lean tools, and the VSM, a vital lean tool

used in visualising and analysing the efficiencies and ineffectiveness in the production process line, and to apply the Monte Carlo sensitivity analysis to identify the short comings in the input parameters. As pioneered by Womark *et al.* (2004), lean manufacturing principles offer a proven methodology for addressing such challenges by reducing waste and improving overall process efficiency. The novelty of this study lies in the fact that the development of a lean-based process for process improvement in rice milling operations using value stream mapping and simulation approach has not been sufficiently reported by the existing literature.

II. LITERATURE REVIEW

Rice is a staple food in Nigeria, and in many countries of the world, its demand has grown exponentially due to increasing population and urbanisation. Despite Nigeria's position as one of Africa's largest producers of rice (KPMG, 2019), its rice milling sector remains largely underdeveloped. For instance, traditional rice milling methods in Nigeria are characterised by low production efficiency, significant waste and high post-harvest losses, accounting for up to 30% of production due to a lack of modernization in Nigerian rice mills (Abdulmalik and Rajgopal, 2007). Chizoba and Anugwu (2022) argued that inefficiencies in processing, such as long lead times and poor-quality control, are critical bottlenecks in any continuous process line.

A. An Overview of Lean Manufacturing

Lean has some varied definitions, however most definitions emphasised identifying and eliminating the waste in a manufacturing flow line, thereby creating value for organisational advantage. It is referred to as a "management philosophy focussed on identifying and eliminating waste throughout a product's entire value stream, extending not only within the organization, but also along its entire supply chain network" (Shah & Ward, 2007). It is also "an integrated manufacturing system' intended to maximise capacity utilisation and minimise buffer inventories by minimising system variability (De Treville & Antonakis, 2009). Lean production is a model where the problem solvers assume the role of thinkers, and their involvement promotes continuous improvement and gives companies the agility they need to face the market demands and environment changes of today and tomorrow (Alves *et al.*, 2012). Jaiprakash and Sangwan (2014) argue that "lean is a production practice that considers the expenditures of resources for any goals other than the creation of values for the end customers to be wasteful, thus a target for elimination."

While lean manufacturing offers significant benefits, its implementation in the Nigerian rice milling sector is underutilised and has marked challenges. Oko and Kang (2015) pointed out that variability in raw material quality and seasonal fluctuations in demand complicate the application of lean tools like Kanban and Heijunka in continuous process industries, such as the rice mills. Abdulmalek and Rajgopal (2007) believe that poor processing contributes indirectly to the capacity deficit because consumers reject inadequately processed rice characterised by a high percentage of impurities like husk and stones as well as under size/broken grains and

concluded by stating that poor quality usually reduces the market values of the product.

Lean Manufacturing, originated from the Toyota Motor Company in Japan (Melton, 2005). It is also known as the Toyota Production System, which was established to increase value-adding activities and reduce waste (Liker & Morgan, 2016). Thus, the application of lean manufacturing and product defects and aims to minimize waste and product defects by increasing value-added activities.

Lean manufacturing technique cut across the entire production value chain from the supply chain to the production shop floor and from the workforce to the managerial level. The principle provides guidance on how to manage and organize the shop floor and the entire business workflows to eliminate waste in the manufacturing process (Black & Black, 2008; Alves *et al.*, 2012; Adeodu *et al.*, 2023). King and Lenox (2002) stated that the Lean Manufacturing philosophy could also be deployed to address environmental objectives. However, the original concept of Lean Manufacturing is tailored towards the delivery of product or services that offer value to the customers without generating wastes (Ikumapayi *et al.*, 2020; Tohidi & Khedrilariviasl, 2012).

B. The Need for Lean Manufacturing

Various sectors, such as production, manufacturing, business, health etc., are increasingly becoming more dynamic and competitive in nature; hence, the need to embrace sustainable waste reduction practices and quality assurance practices. For business organisations to achieve their bottom-line goals of profitability, improved product quality, and customer satisfaction, there is a need to add value to production processes. The Lean manufacturing approach can assist manufacturing industries in identifying the root cause of wastes to effectively mitigate them (Sunder & Antony, 2018). The approach promotes adherence to best practices, optimization of manufacturing shop floor and inventory, improvement in productivity and product's quality, reduction in manufacturing lead time, and non-value-adding activities via effective flow of materials and manufacturing resources (Sunder & Antony, 2018). The lean manufacturing principle seeks operational excellence by ensuring production processes run effectively and efficiently. Wastes can affect an organisation's production level, level of customer satisfaction, as well as profitability, competitiveness, and sustainability of the manufacturing industries. Some of the lean manufacturing techniques include the Just-in-Time (JIT), Kanban system, Kaizen approach, production smoothing, and Value Stream Mapping (Roriz *et al.*, 2017).

Some manufacturing industries adopt the "just-in-case" production approach, which may result in over-production as opposed to the manufacturing principle of "just-in-time," whereby products are manufactured according to the volume of demand (Sunder & Antony, 2018). The "just-in-time" principle reduces the holding cost of inventory and increases the inventory turnover via the production of the exact volume of product at the right time based on demand.

The Kanban tool presents a systematic approach to ensure a gradual, orderly, and continuous flow of materials and parts to promote effective inventory control and reduce defective

parts during manufacturing. On the other hand, the Kaizen tools, involve the 5S, which represents "sort", "set in order", "shine", "standardize" and "sustain". The production smoothing concept aims to achieve a balance in the production schedule so that resources can be effectively utilised to produce the right quantity of products.

Value Stream Mapping (VSM) is suitable for analysing the flow of materials in the production chain to identify and eliminate wastes (Roriz *et al.*, 2017; Magodi *et al.*, 2022a), while quality management tools are tools used to identify and mitigate the root causes of variations or problems within a manufacturing to improve production efficiency and product's quality. This includes Total Quality Management (TQM), and Six Sigma techniques (Magodi *et al.*, 2022a). The lean tool is appropriate for production process monitoring and continuous process improvement. Some of the lean tools include control charts, Pareto charts, cause-effect diagram, check sheets, histogram, scatter charts, Stratification (Flow charts, fish bone diagram, and run charts) (Magodi *et al.*, 2022a). Thus, lean manufacturing comprises a set of principles aimed at identifying and eliminating waste and improving customer's satisfaction. Existing works have reported on the successful implementation of the lean based approach for waste reduction, as well as improvement in process cycle efficiency in the areas of manufacturing (assembly operations), health, education, banking sectors (Roriz *et al.*, 2017; Marodin *et al.*, 2017; Tortorella *et al.*, 2017; Sunder & Antony, 2018; Sunder & Mahaligam, 2018; Magodi *et al.*, 2022a).

Wastes are considered as any non-value-added activity that does not contribute to the development of the final product (Hines *et al.*, 2004). They consume resources and reduce the overall efficiency of the process cycle. Sutrisno *et al.* (2018), identified differ categories of wastes namely unnecessary transportation, excessive inventory, unnecessary motion, queue or waiting, overproduction or, overprocessing, redundancy, and defects (Roriz *et al.*, 2017; Sutrisno *et al.*, 2018) while Vinodh *et al.* (2011) added two more categories of wastes namely underutilization of human resources and environmental waste.

Existing works have been on discrete manufacturing techniques; few works have been carried out on the continuous process industries. A review of literature such as Panwar *et al.* (2017) and Maware *et al.* (2020) reveal shortcomings in the number of works done on continuous process industries to the works to the discrete manufacturing processes. This research work was necessitated to close those gaps especially in the rice production industry. Okocha and Wan Daud (2021) contended that "the failure in managing lean implementation process is often consolidated to poor mind-set and inadequate understanding of the lean concept itself by managers."

Research has demonstrated that lean manufacturing concepts, typically applied in the automotive and electronics industries, can be effectively adapted to rice milling, a continuous process industry. This is contrary to the general belief that lean cannot be applied successfully in process industries, as expressed in a literature review (Panwar *et al.*, 2017; Maware *et al.*, 2020).

Abdulmalek and Rajgopal (2007) stated in their study that "rice processing and production is one of the leading industries

in the world for food security and sustainability". However, the same industry had struggled all through the years with the impediments mitigating its contribution to economic growth in Nigeria. Significant improvement in rice production will create an international hub for African manufacturers and businesses. Hence, investors can embrace lean principles to achieve improved productivity, and continuous waste improvement Maware *et al.* (2020), as well as Magodi *et al.* (2022b) suggested the implementation of lean manufacturing principles in manufacturing-based sectors ranging from small to medium and large scale organisations in the developing and developed countries for improved productivity and manufacturing efficiency.

III. METHODOLOGY

This section details on the lean manufacturing technique employed to identify and address key issues resulting in process inefficiency and waste generation in the 50-metric-ton rice milling facility. The technique identified various inefficiencies in the rice milling facility and implement targeted improvements. The IGrafx software was employed in formulating and modelling the existing state value stream map (CSVSM) which shows the process steps and identifies areas of waste on the processing line. Line balancing charts are drawn through simulation to identify imbalances in the process flow to optimise workflow at various workstations and increase process efficiency. Further analyses were conducted using the Monte Carlo sensitivity analysis with the aid of Python programs to analyse the relationship between metrics such as productivity, quality, cost, and on-time delivery vis-à-vis other metrics such as cycle time, lead time, inventory, work-in-progress, finished goods, value-added time, production efficiency, defect rate, and on-time delivery.

A. Research Design

This study adopts a mixed-methods approach, combining qualitative and quantitative analysis to investigate and address inefficiencies in the rice milling facility. The methodology is divided into five key phases:

- Data collection and baseline analysis
- Process mapping and waste identification
- Lean tool selection and implementation
- Simulation and validation
- Performance evaluation and continuous improvement

B. Data Collection and Baseline Analysis

Data were collected based on direct observations of milling operation as well as interviews with machine operators, and line managers by the team of investigators to understand areas of bottlenecks. Also, historical production records were provided for average cycle and lead times, defect rates, and inventory levels. The team also took a time motion study to measure process durations and variability. This measurement is aimed at determining the existing state of the production process so as to seek ways to improve areas of inefficiencies using the lean tools. The baseline data collected on the facility's existing operations were to establish a performance benchmark. The average values of the data collected are:

- Cycle time: 17,544 sec

- Lead time: 147,000 sec
- Value-added time (VAT): 1916 sec
- Inventory levels: Raw material (74.3 MT)
- Work-in-progress (27.87 MT)
- Finished goods (43 MT)
- Production efficiency: 7.7%
- Equipment availability: 75%
- Defect rate: 12%
- On-time delivery: 43%

C. Mathematical Equations

The lead time (LT), which is the time taken to complete the rice processing from the ordering date to the delivery date, while the PCE, which measures the percentage of time spent on value-adding activities, are expressed by Equations 1 and 2 respectively.

$$LT = VAT + NVAT \quad (1)$$

$$PCE = \frac{VAT}{TCT} \times 100 \quad (2)$$

Where TCT is the total cycle time (sec)

D. Process Mapping and Waste Identification

A comprehensive Value Stream Map (VSM) was developed to visualise the existing state of operations, highlighting value-added and non-value-added activities. It was selected for use in this study because it is suitable for mapping material and information flow. It also provides a holistic representation and enable a comprehensive visualisation of an entire process thereby permitting quick identification of wastes and root causes of inefficiencies in the process (Daniyan *et al.*, 2022 Adeodu *et al.*, 2023). Existing studies identified the seven types of waste - overproduction, waiting, transport, over-processing, inventory, motion, and defects (Xia & Sun, 2013). The bottlenecks and inefficiencies identified in the rice production facility using these lean principles are:

- Excessive waiting time due to equipment downtime
- High Work-In-Progress (WIP) levels caused by batch processing
- Quality issues leading to a high defect rate
- Delays in fulfilling customer orders due to inefficient scheduling

Table 1 presents the processes involved in rice production and the calculated process cycle efficiency (PCE) while Figure 1 presents the VSM of the existing process. These six major processes are winnowing, parboiling, drying, de-stoning and milling, colour sorting and packaging.

Table 1: The processes involved in rice production and the calculated process efficiency for the existing process

S/N	Process	Description	Cycle time (sec)	Value added time (sec)	Process cycle efficiency (%)
1.	Winnowing	This is the process by which the rice is separated from unwanted materials such as chaff.	2880	1440	50
2.	Parboiling	This is a hydro-thermal treatment of the paddy rice involving soaking in water and steaming to obtain gelatinized rice. The essence is to improve the quality and texture of the rice and make it harder, and to seal the cracks within the rice to obtain a higher yield with less breakage	2652	1542	58.1
3.	Drying	This involves the removal of moisture from the parboiled rice	3480	2220	63.8
4.	De-stoning and milling	This process improves the rice quality by removing stones, impurities and broken grains from it	3180	2400	75.5
5.	Colour sorting	This process employs machine embedded with sensor and camera to sort rice by colour into different brands or grades automatically	2592	1752	67.6
6.	Packaging	This is the final step involving the sealing and enclosure of rice to preserve it from contamination and make it easy for transportation, delivery, or storage	2760	2142	77.6
TOTAL			17,544	11,496	65.5

The study objective is to appraise the state of the operations at various points in the manufacturing value chain using the existing state value stream map (ESVSM) and seek improvement where there are inefficiencies. The study also seeks to reduce the manufacturing lead time of the processes involved in rice production without compromising the quality of the final product.

Table 2 presents the calculated metrics values of the rice processes for the existing process while The PCE measures overall process efficiency for the existing rice production processes is calculated as 65.5% using Equation 2.

Table 2: Calculated metrics values of the rice processes for the existing process

S/N	Metrics	Value
1.	Total lead time (sec)	149,683
2.	Overall value-added time, VAT (sec)	11,496
3.	Overall non-value added time, NVAT (sec)	6048
3.	Total cycle time (sec)	17,544
4.	Time for raw material procurement and movement (sec)	40,500
5.	Work-In-Progress time (sec)	109,182
6.	Overall process efficiency (%)	65.5

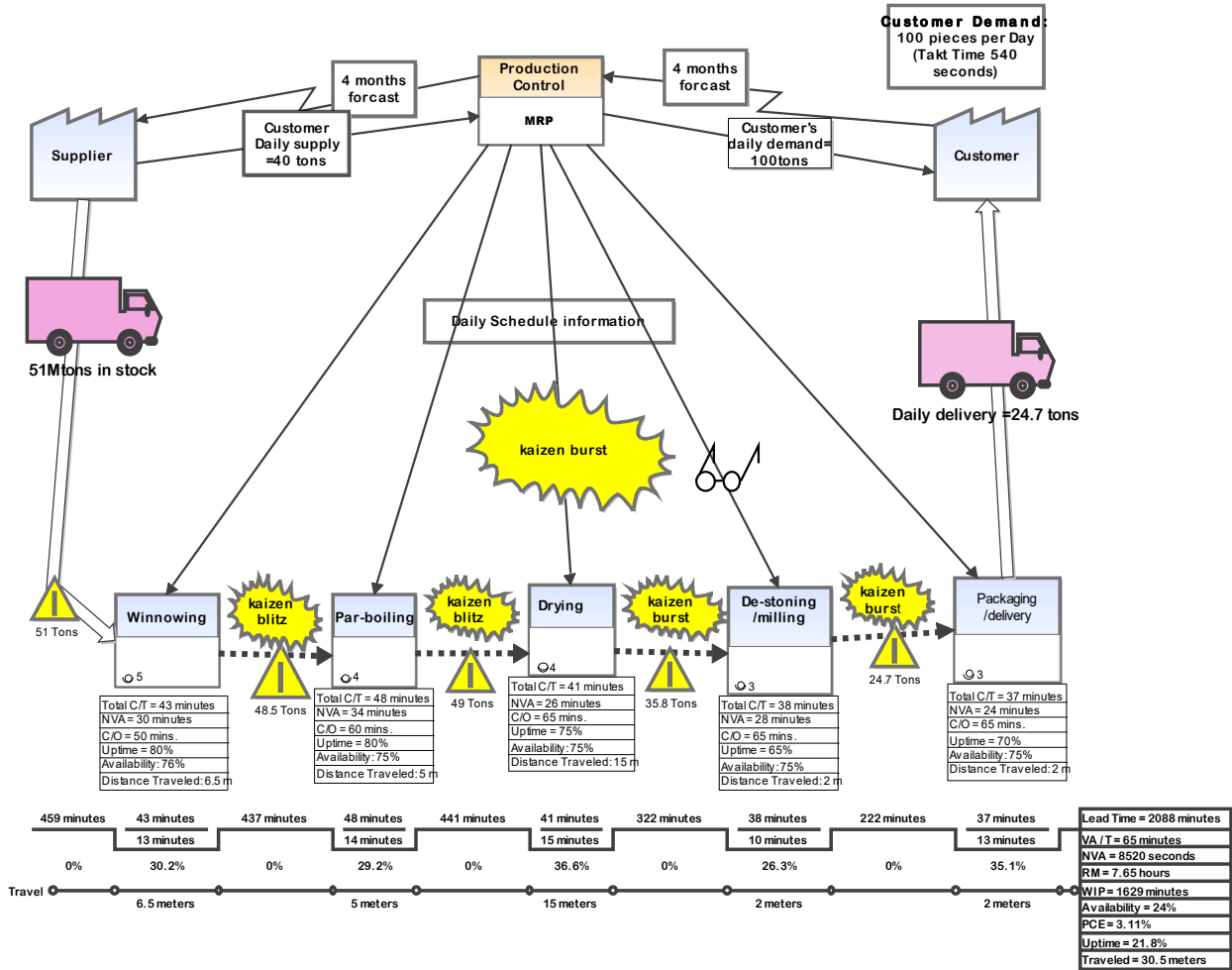


Figure 1: VSM of the existing process

Figure 2 presents the line balancing chart for the 50 metric tons. The line balancing chart is used to visualise the process to identify the ways to improve it by balancing the process steps necessary to meet customer's demands. The figure shows the six workstations for the rice production processes. The goal of the line balancing chart is to balance the time spent on each workstation to match the takt time. The takt time represents the time it takes to complete a product to meet customer's demand. A perfectly balanced production line is one in which the actual takt time equals the planned takt time. As shown in Figure 2, there is a slight difference in the actual takt time and the planned takt time which implies that the production line is not properly balanced and as a result there is a slight mismatch between the rate of production and the takt time.

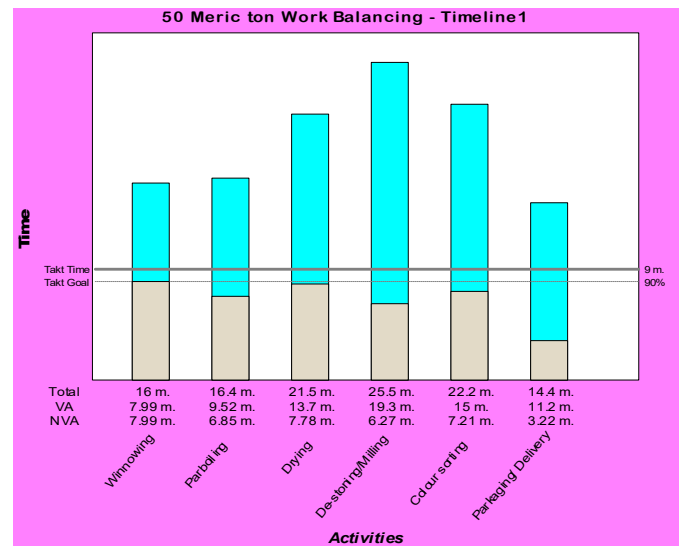


Figure 2: Line balancing chart for the 50 metric tons

E. Simulation and Validation

The lean improvement process was simulated using the Monte Carlo methods with the aid of Python programs. A model of the existing production system was created to analyse the impact of proposed interventions. The simulation focused on:

- Measuring reductions in lead time and cycle time.
- Evaluating changes in inventory levels, defect rates, and on-time delivery.
- Testing various scenarios to identify the optimal combination of lean tools.
- Correlation between performance metrics such as productivity, quality, cost, and on-time delivery vis-à-vis other metrics such as cycle time, lead time, inventory, work-in-progress, finished goods, value-added time, production efficiency, defect rate, and on-time delivery.
- The simulation results were validated against real-world data collected after implementing initial improvements.

IV. RESULTS AND DISCUSSION

This section presents the outcome of the implementation of the Lean tools, the results obtained from the simulation analysis as well as discussion of results.

A. Outcome of the implementation of the Lean Tools

Waste generation contributed to non-value adding times and ultimately low process cycle efficiency in the existing process. This was identified by mapping out the existing process and improved by streamlining the operations to reduce redundancy and wastes generation. This led to the streamlining of the processes from six processes to four, merging the parboiling and drying processes as well as the colour-sorting

process with the milling and de-stoning processes. The more compact the production process is, the lesser the amount of wastes generated and vice versa. To ensure ease of material flow, practice of First-in-First-Out (FIFO) was introduced as shown in Figure 3. Stocks are properly sorted and labelled for ease of identification and overcrowding of stocks was eliminated.

The overall PCE for the existing rice production processes is calculated as 65.5% using equation 2. This value of PCE is lower than the organisation’s target of 85%. This can be attributed to wastes generated in the processes due to non-value added times which increased the total lead time of rice production processes. Figure 3 shows the new VSM following the implementation of lean tools which brought about reduction in the waste generated and improvement in the process cycle efficiency. Comparing Figure 1 (VSM for the existing process) to Figure 3, it can be seen that six activities that form the rice processing operations have been streamlined to four following the implementation of the lean technique. The parboiling and drying processes as well as the colour-sorting process with the milling and de-stoning processes have been streamlined in the new state value map. Post-implementation data were collected to evaluate the impact of lean interventions on key performance metrics. The new state value stream map visualises the expected operational base with the optimised production. The results shows that there is significant improvement in the rice processing step following the implementation of the lean tool in terms of efficiency, reduced defects, processed quality rice, and on-time delivery to the customers. The line balancing chart in Figure 4 shows a balanced operation, with each workstation showing compliance with the Takt time of 540 seconds per unit of rice processed.

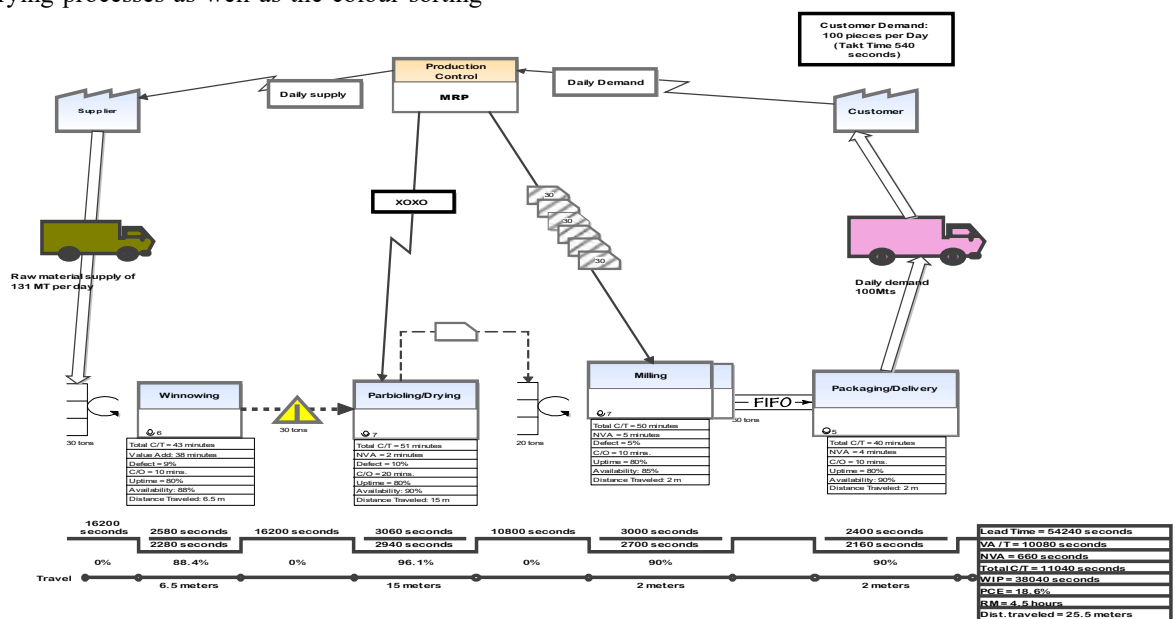


Figure 3: New state value stream map

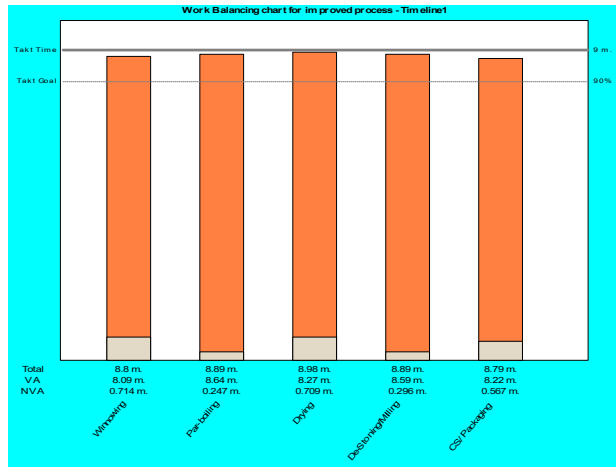


Figure 4: The line balancing chart for the 50 metric tons after improvement initiatives are applied.

Table 3 presents the major processes involved in rice production and the calculated process cycle efficiency (PCE) for new processes. Comparing Table 1 (for the existing process) with Table 3 (new process), it is obvious that the cycle time reduces from 17,544 sec to 10,326 sec, accounting for a 41.11% reduction. The lower the cycle time, the lower the time of production and vice versa. Furthermore, the implementation of the lean tool streamlined the processes from six processes to four, merging the parboiling and drying processes as well as the colour-sorting process with the milling and de-stoning processes. However, value-added time decreased from 11,496 sec to 9,726 sec after the implementation of the lean tool. This may be attributed to the merging of the parboiling and drying processes as well as colour-sorting process with the destining and milling processes which resulted in streamlined operations. By streamlining the operations, the process cycle efficiency was observed to increase with reduction in non-value added activities.

The study objective is to appraise the state of the operations at various points in manufacturing value chain for the new state value stream map (FSVSM) following the implementation of the lean tool.

Table 3: Rice production processes and the calculated PCE for the new process

S/N	Process	Cycle time (sec)	Value added time (sec)	Process cycle efficiency (%)
1.	Winnowing	2220	2040	91.9
2.	Parboiling and drying	4440	4200	94.6
3.	De-stoning, milling and colour sorting process	1802	1743	96.7
4.	Packaging	1864	1743	93.5
	Total	10,326	9726	94.18

The overall PCE for the new rice production processes is calculated as 94.18%. This is a significant improvement over the existing process with PCE of 65.5%. This value of PCE exceeds the organisation’s target of 85%. This implies that with the implementation of continuous improvement lean tools, the organisation can exceed their estimated target of PCE.

Table 4 presents the comparative analysis of calculated metrics values for the rice processes for the existing and new processes. The results obtained indicated that the new process will significantly improve compared to the existing process following the implementation of the lean tools.

Table 4: Calculated metrics values of the rice processes for the new process

S/N	Metrics	Value for the existing process	Value for the new process	% difference
1.	Total lead time (sec)	149,683	58,020	61.24
2.	Overall value added time, VAT (sec)	11,496	9726	15.40
3.	Overall non-value added time, NVAT (sec)	6048	600	90.08
3.	Total cycle time (sec)	17,544	10,326	41.14
4.	Raw material time (sec)	40,500	14,400	64.44
5.	Work-In-Progress time (sec)	109,182	43,620	60.04
6.	Overall process cycle efficiency (%)	65.5	94.18	28.68

B. Performance Evaluation and Continuous Improvement

Figure 5 shows the comparative analysis of the existing and new processes based on some performance metrics such as total lead time (TLT), value added time (VAT), non-value added time (NVAT), total cycle time (TCT), raw material (RM) and work-in-progress (WIP). From there results obtained, there was significant improvements in performance of operation after applying all the improvement techniques with necessary lean tools and methods.

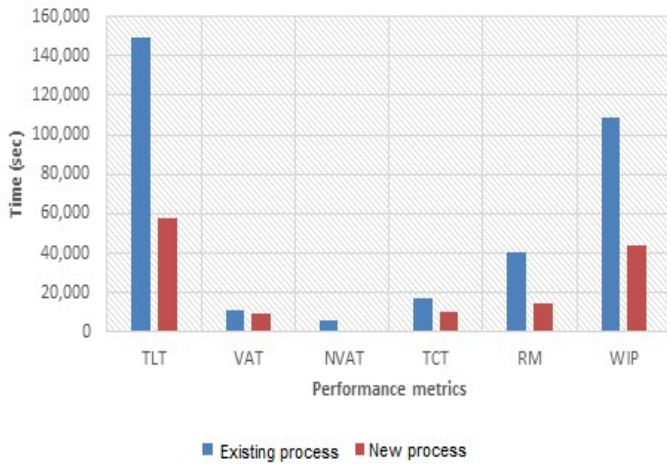


Figure 5: Comparative analysis of the existing and new processes

Following the implementation of the VSM and the streamlining of the operations significant improvements were achieved against baseline data to assess the effectiveness of the lean transformation. The improvement include the following:

- Reduction in lead time by 61.24%
- Reduction in cycle time by 41.14%
- Reduction in non-value added time by 90.08%
- Reduction in raw material movement time by 64.44%
- Improvement in WIP by 60.04%
- Improvement in overall process cycle efficiency by 28.68%

C. Outcome of the Simulation Analysis (Correlation between Performance Metrics)

The results of the Monte Carlo method of sensitivity analysis using python programs are presented in Figures 6-9. The figures show the quality between metrics such as productivity, quality, cost, and on-time delivery vis-à-vis other metrics such as cycle time, lead time, inventory, work-in-progress, finished goods, value-added time, production efficiency, defect rate, and on-time delivery.

In the analysis, considerations were given to the impact of reducing cycle time on the system behaviour. Likewise, the impact of reducing defects rates, work in process, and increasing value added time was considered. The variability in the distribution of the mean of the parameters is also considered.

Figure 6 (a & b) shows the correlation between productivity and other baseline metrics at 5% and 10% distribution. The figure indicates that productivity has a strong positive correlation with Value Added Time (0.71385) while having strong negative correlation with cycle time of 0.713330. This implies that productivity increases with increase in value added time and decrease in production cycle time and vice versa. However, the dispersion in the distribution in cycle time is

more in the 10% distribution than that of the 5% indicating typical variation expected in the cycle time.

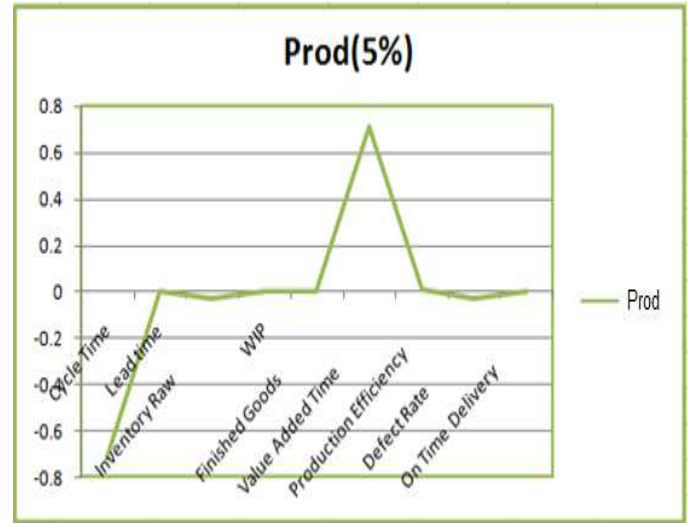


Figure 6(a)

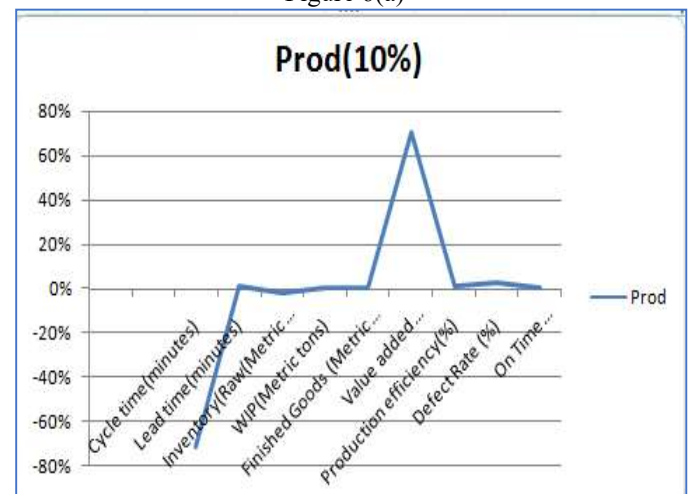


Figure 6(b)

Figure 6 (a & b): Correlation between productivity and other baseline metrics

Figures 7(a & b) shows the correlation between quality and other baseline metrics at 5% and 10% distribution. The experiment involves both the 5% and 10% distribution around the mean values. The defect rates is perfectly negatively correlated (-1.000) with quality. This implies that product quality improves with reduction in the rate of defect and vice versa. The spread in standard deviation round the mean of value of 5% indicates expected variability in WIP levels with improved productivity performances than the 10% distribution.

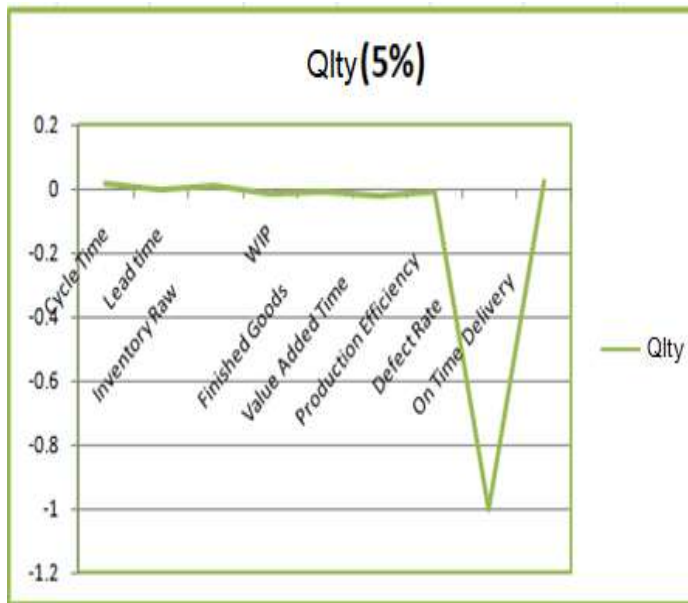


Figure 7 (a)

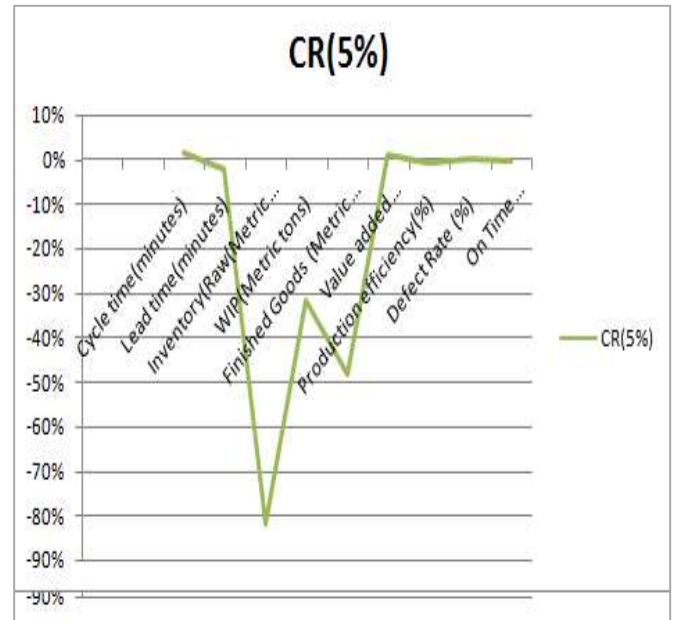


Figure 8 (a)

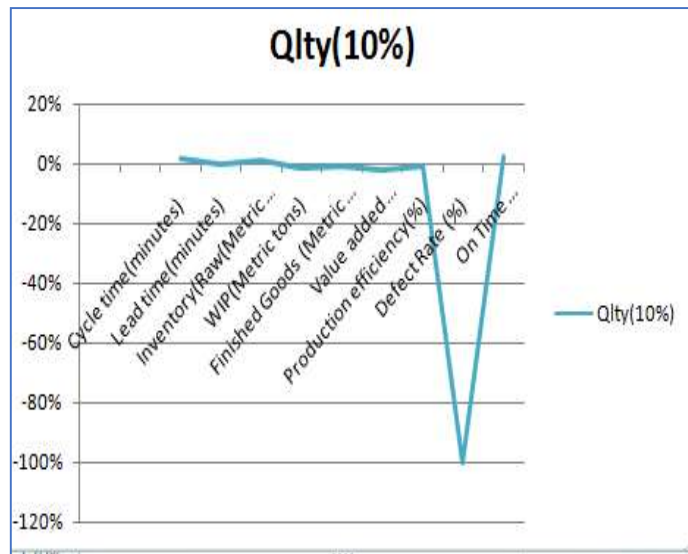


Figure 7

(b)

Figure 7 (a & b): Correlation between quality and other baseline metrics

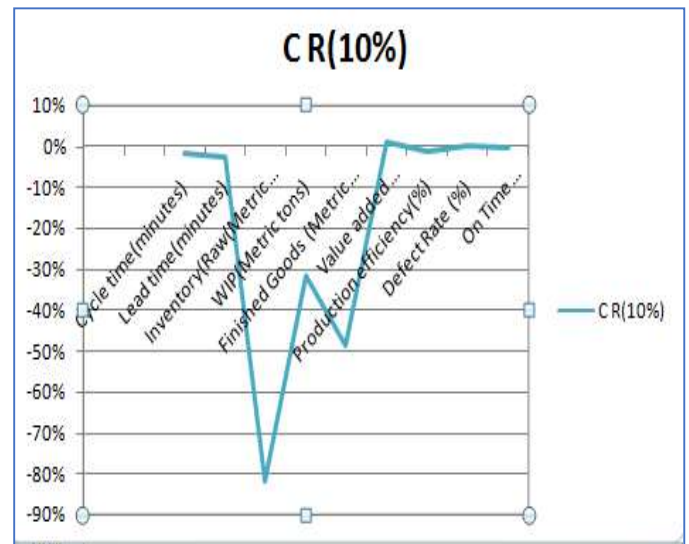


Figure 8(b)

Figure 8(a & b): Correlation between cost and other baseline metrics

Figure 8 (a & b) shows the correlation between cost and other baseline metrics at 5% and 10% distribution. The results show that inventory level is negatively correlated with cost. This implies that higher inventory levels, as well as natural inventory level fluctuations, lead to reduced cost efficiency. This implies that cost efficiency may improve with the practice of JIT.

Figure 9 (a & b) shows the correlation between on-time delivery and other baseline metrics at 5% and 10% distribution. There is a negative correlation between on-time delivery with defect rate (-0.025395) with other correlations kept minimal, indicating that variations in the other parameters, having a negligible impact on On-time delivery within the given ranges reflecting typical variability in on-time delivery. Furthermore, the lower the rate of defect in the process or product the higher the rate at which the product is delivered to customers and vice versa.

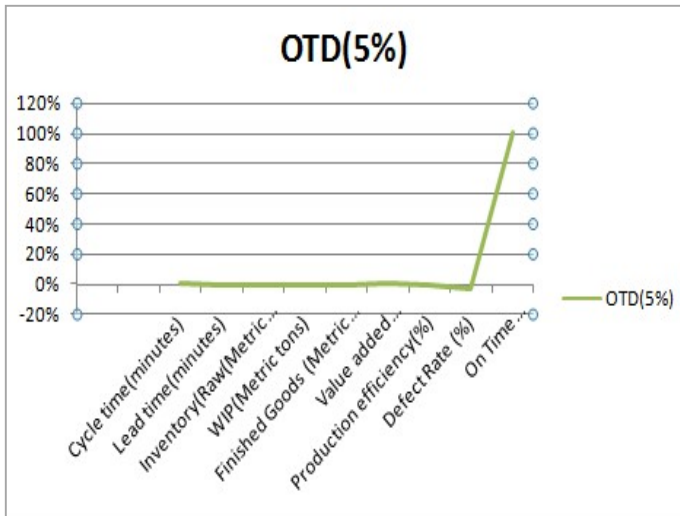


Figure 9 (a)

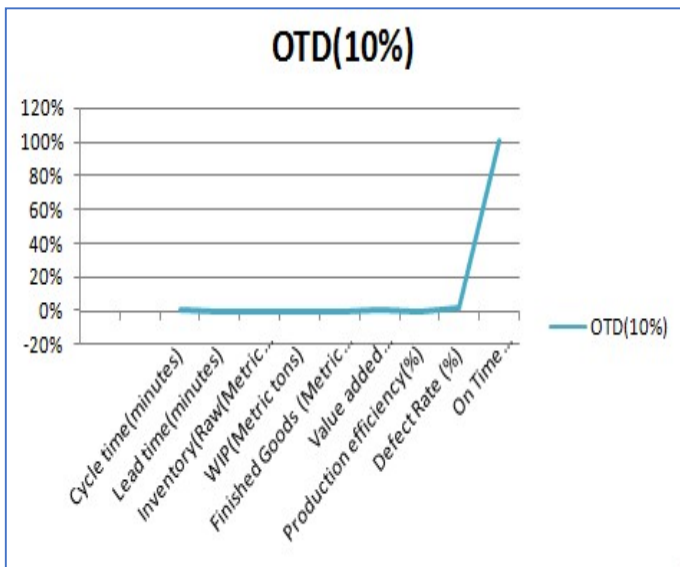


Figure 9 (b)

Figure 9 (a & b): Correlation between on-time delivery and other baseline metrics

The outcome of the simulation analysis demonstrates potentials for improvements the following areas:

- Reduction in defect rates by 25%.
- Improvement in equipment availability by 14%.
- Improvement in on-time delivery performance by 57%.
- Reduction in distance travelled reduced by 66.1%.
- Improvement in production efficiency improved by 73.2% with a throughput rate of 0.00172 Mts/day after improvement as against the former throughput rate of 0.00046 Mts/day.
- Reduction in down time and improved machines uptime.

- Enhanced customer satisfaction and improved overall operational efficiency.

D. Discussion of Results

This structured approach provided a comprehensive roadmap for transforming the 50-metric-ton rice milling facility into a lean, efficient operation. The application of the lean tools to enhance an existing rice processing activities at a rice milling facility proved useful. There was significant improvement in the state of the new process in terms of reduction in the lead time, cycle time, raw material movement time and non-value added time with improvements in work in progress and overall process efficiency. The outcome of this study agrees significantly with the results from the existing studies that the implementation of lean tools could improve process cycle time and efficiency, value added time, productivity and on-time delivery to customers amongst others amongst others (Roriz et al., 2017; Marodin et al., 2017; Tortorella et al., 2017; Sunder & Antony, 2018; Sunder & Mahaligam, 2018; Magodi et al., 2022a).

Furthermore, the simulation analysis shows prospects for improvement in material flow, machine and equipment management, personnel orientation and training, warehouse and logistics arrangement, work environment and processes improvement the lean tool is effectively deployed for continuous improvement in the rice processing facility. Based on this study, three continuous improvement approaches are suggested.

First, waste impact assessment are recommended at every stage of the process including waste classification and economic loss attached to each class of the wastes generated. This will enhance understanding areas where waste is generated for effective mitigation. Second, critical task identification, classification, and priority ranking should be conducted (Cagliano et al., 2018). Finally, there is a need for the establishment of an organisation culture that encompasses a customer and employee-centered culture to facilitate effective decision-making and enhance continuous improvement. Existing studies indicated that lean awareness at all organisation’s levels of the organisation is imperative for sustaining the implemented lean principle (Bhasin & Bucher, 2006; Sunder et al., 2019). The non-implementation of the lean tool and principles initially resulted in low process efficiency principles, however, by imbibing a culture of lean practices, the organisation could achieve significant continuous improvement (Henderson et al., 1999).

The application of value stream mappings to identify shortcomings and areas of bottlenecks in the rice production process and Monte Carlo sensitivity analysis conducted with the aid of python programs to investigate the impact of the lean tools and correlation between performance metrics represent a major contribution to knowledge.

V. CONCLUSION

A. Conclusion

This research work focuses on using a lean based process improvement technique to improve on the rice production processes, a continuous process industry situated in Otukpo,

Benue State. The value stream map technique visualised the existing rice milling process operations to identify the wastes generated and areas of improvements. After all the improvements processes were applied on the existing milling operations, the new process shows a significant improvement in the milling process. This is evidenced in the improvement in the state of the new process following the implementation of the lean tool. The results of the new state value stream map (NSVSM) present a reduction in the following areas: lead time by 61.24%, cycle time by 41.14%, raw material movement time by 64.44% and non-value added time by 90.08%, with improvements in work in progress by 60.04% and overall process efficiency by 28.68% following the implementation of the lean tool. The process cycle efficiency of the new process increased to 94.18% from 65.5% exceeding the targeted process efficiency of 85% by the organisation.

Using Monte Carlo sensitivity analysis conducted with the aid of Python programs, variations were discovered indicating waste in the process line, which are due to certain underlying factors such as high inventory rates, defects, overproduction, over-processing, motion or movement of workers, transportation of raw materials and waiting or delays in the production process. Such delays were caused by frequent downtime observed and high inventory rates resulting in bottlenecks at some workstations. The outcome of the simulation showed show potential improvement in the overall production efficiency by 73.2%. There were also potential improvements in the areas of productivity, products quality, reduction in cost of products and time of delivery to customers and after the simulation.

Thus, this study may assist process industry in achieving process improvement. Therefore, it is concluded that keeping a minimal variation in the process greatly affects it progressively. Reducing cycle time and increasing VAT have a positive impact on productivity rates, while improving defect rates improves quality and on-time delivery rates.

These findings may drive management decisions aimed at improving process cycle time and efficiency, inventory, set up time, value added time, productivity, quality, cost of products and on-time delivery to customers.

B. Recommendations

Based on the outcome of this study, three continuous improvement approaches are recommended. First, waste impact assessments are recommended at every stage of the process, including waste classification and economic loss attached to each class of waste generated. This will enhance understanding areas where waste is generated for effective mitigation. Second, critical tasks identification, classification and priority ranking should be conducted. Finally, there is a need for the establishment of an organizational culture that encompasses a customer and employee-centered culture to facilitate effective decision-making and enhance continuous improvement.

This study provides a practical, lean-based guideline for optimising the resources in a rice production facility to promote process efficiency and customer satisfaction. The study emphasised the use of lean tools for value creation and waste reduction. Future works can consider the integration of

six sigma framework to the lean approach to achieve waste reduction and quality improvement in the rice production facility.

AUTHOR CONTRIBUTIONS

A. O. Oko: Conceptualization, Data curation, Fund acquisition, Investigation, Methodology, Project Administration, Resources, Software, Validation, Visualization, Writing – original draft. **S. C. Nwanya:** Conceptualization, Data curation, Fund acquisition, Investigation, Methodology, Project Administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft., Writing – review & editing. **E. C. Okorigwe:** Conceptualization, Fund acquisition, Software, Validation, Methodology Writing – original draft. **H. C. Godwin:** Conceptualization, Fund acquisition, Software, Validation, Methodology, Writing – original draft **I. A. Daniyan:** Data curation, Fund acquisition, Software, Validation, Methodology, Writing – review & editing. **H. S. Phuluwa:** Data curation, Fund acquisition, Software, Validation, Methodology, Writing – review & editing.

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