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Deployment of Lean Manufacturing in Palm Oil Mill for Maximum Yield: A Case Study of Leading Palm Oil Producer in Nigeria

Oba, D. K. [a*], Uche, R. [a], Nwufo, O. C. [a], Obiukwu, O. O. [a], Nwankwo E. I. [b], and Ekpechi, D. A. [a]

[a] Department of Mechanical Engineering, Federal University of Technology, Owerri, Imo State, Nigeria.
[b] Department of Mechanical Engineering, Chukwuemeka Odumegwu Ojukwu University, Anambra State, Nigeria.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The deployment of lean manufacturing in the palm oil mill companyaimed at maximizing yield, was thoroughly investigated. The company has been experiencing a decline in palm oil production, adversely affecting productivity and customer satisfaction. The methodology employed for optimization encompassed a comprehensive system description, detailing the case study company's history, operational modalities, production machinery, and system challenges. To gather a holistic understanding of the company's current situation, data was meticulously collected through

**Corresponding author: E-mail: desmondoba123@gmail.com;*

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questionnaires, examination of company records, and other relevant sources. Microsoft excel software was then utilized to analyze the acquired data. The implementation of lean manufacturing tools, such as the fishbone diagram, identification of eight deadly wastesand takt-timeplayed a pivotal role in streamlining operations. In addition, a quantitative model of the supply chain was applied, utilizing critical path method (network analysis) to determine the optimal route. The results derived from the application of lean manufacturing tools and the supply chain quantitative model exhibited a remarkable improvement between (2012-2016) and (2018-2022). The average oil palm extraction increased substantially from 8.67% (2012-2016) to an impressive 30.52% (2018-2022). Furthermore, the management tools led to a significant reduction in machine downtimes, decreasing from an annual average of 5,498.6 hours to 2,472.4 hours. This improvement resulted in a considerable reduction in the annual total average cost of machine maintenance, plummeting from #1,899,578.6 to #261,853.8. The optimization efforts also extended to the supply chain, where selecting Path-2, exhibiting the least total supply time of 11 hours, significantly reduced the cost of supply from an average of #2,168,402 to #1,893,186. Overall, the net revenue of the company witnessed a remarkable surge of 71.99% post-implementation of these management tools. This comprehensive approach not only addressed production challenges but also had a substantial positive impact on the company’s financial performance. The strategic deployment of lean manufacturing emerged as a catalyst for sustainable growth and enhanced operational efficiency.

Keywords: Lean manufacturing; supply chain; takt-time; eight deadly waste; productivity; sustainability.

1. INTRODUCTION

The manufacturing industry is undergoing a profound evolution, driven by the imperative of improved efficiency, product quality, and cost reduction. Manufacturers worldwide are prioritizing the delivery of high-quality products while minimizing resource wastage to meet customer demands. Waste reduction remains a formidable challenge, despite the adoption of strategies like lean manufacturing, which aims to optimize resource utilization [1-2]. In Nigeria, the manufacturing sector has observed minimum growth due to some factor which includes inadequate and dilapidated infrastructures, minimum knowledge and application of advanced management tool by the staff, government policies and other issues, these factors do not only affect manufacturing negatively, some companies have collapsed in Nigeria due to these issues as presented in Table 1, illustrating some failed companies and the reason to their failure.

To cub these menace that causes failure in manufacturing and service rendering companies, some exceptional manufacturing tools and methods such as computer aided design and manufacturing (CAD/CAM), lean manufacturing, value stream mapping, kaizen, six sigma, total quality management (TQM), supply chain analysis, just-in-time (JIT) production, and other management tools [5].

Lean manufacturing is a systematic approach derived from the Toyota Production System, aimed at reducing waste and optimizing production processes [6]. Widely embraced across industries, it emphasizes waste reduction, operational streamlining, and value enhancement for customers. Key principles include addressing eight deadly wastes, implementing tools like Heijunka and Kanban, and fostering a culture of continuous improvement through Kaizen. Lean methodologies prioritize efficiency, productivity, and customer satisfaction through the elimination of non-value-added activities [7-9].

Supply chain analysis is a crucial production and management tool that involves the examination and optimization of the entire process of sourcing, production, and distribution of goods or services. It enables businesses to identify inefficiencies, streamline operations, and maximize overall efficiency [10-11]. By analyzing each step in the supply chain, from raw material acquisition to delivery of the final product to the end customer, organizations can identify bottlenecks, minimize costs, and enhance customer satisfaction. Supply chain analysis also facilitates better decision-making by providing insights into inventory management, production scheduling, and supplier relationships. Ultimately, it helps businesses gain a competitive edge by improving agility, reducing lead times, and ensuring the smooth flow of goods or services through the entire supply chain ecosystem [12-13].

Table 1. Failed companies in Nigeria and causes [3-4]

Industry	Company	Year Failed	Reasons for Failure
Textile	United Nigeria Textiles (UNTL)	2007	High cost of production, inadequate infrastructure, competition from imported textile products, and policy inconsistency.
Steel	Jos Steel Rolling Company (JSRCL)	2006	Inadequate power supply, reliance on imported raw materials, outdated technology, lack of government support, and policy inconsistency.
Paper	Nigerian Paper Mills	2017	High cost of raw materials, inadequate infrastructure, competition from imported paper products, and lack of modernization and technology.
Automobile Manufacturing	Peugeot Automobile Nigeria (PAN)	2019	Lack of government support and policy inconsistency, competition from imported vehicles, inadequate infrastructure, and high cost of production.
Agriculture	Nigerian Agricultural Cooperative Bank	2001	Inadequate funding, lack of access to finance, climate change and unpredictable weather patterns, inadequate infrastructure, poor agricultural practices, and lack of modernization.
Cement	Nkalagu Cement Company (NIGERCEM)	2002	Over-dependence on imported equipment and machinery, inadequate infrastructure, policy inconsistency, and competition from imported cement products.
Pharmaceutical	Smithkline Beecham Nigeria (Now GlaxoSmithKline)	2001	Counterfeit drugs, inadequate regulation and enforcement, reliance on imported raw materials, high cost of production, and lack of research and development.
Shipbuilding	Nigerian National Shipping Line (NNSL)	1995	High cost of production, lack of skilled labor, inadequate infrastructure, reliance on imported components, and competition from foreign shipyards.
Oil Palm	Ondo State Oil Palm Company (OSOPADEC)	2009	Land tenure issues, inadequate infrastructure, low productivity, smuggling of palm oil, competition from other oil-producing countries, and lack of government support.
Mining	Nigerian Mining Corporation	2005	Illegal mining activities, lack of infrastructure, environmental degradation, inadequate regulation and enforcement, insecurity in mining areas, and reliance on outdated technology.
Telecommunications	NITEL (Nigerian Telecommunications Limited)	2006	Inadequate infrastructure, high cost of internet access, poor quality of service, unreliable power supply, competition from foreign telecom companies, and government regulation.

Table 2. Operation stages of the production

Stage	Description
Palm Fruit Plantation	Extensive oil palm plantations for cultivating oil palm trees, the primary source of fresh fruit bunches (FFBs).
Harvesting	FFBs harvested from plantations, using skilled laborers or mechanical harvesters.
Fruit Reception	Harvested FFBs weighed and inspected for quality; substandard or damaged FFBs sorted out.
Sterilization	FFBs subjected to sterilization, typically using steam, to kill microorganisms and loosen fruit from bunch.
Threshing	Mechanically threshed sterilized FFBs to separate palm fruit from the bunch, leaving empty bunches behind.
Digestion	Palm fruit heated in a digester with hot water or steam, softening the fruit and separating oil from fibres.
Pressing	Mixture of palm oil, water, and fibers passed through a mechanical press, extracting crude palm oil.
Clarification	Crude palm oil heated to separate from water and solid particles; clean oil skimmed off.
Purification	Further purification to remove impurities, often using centrifuges or equipment, achieving cleaner oil.
Drying and Packaging	Purified palm oil dried to remove moisture, then packaged in containers or drums for distribution and sale.
Waste Management	Management of generated waste, including palm oil cake and empty fruit bunches, with sustainability in mind.

The palm oil industry is a significant player in the global economy, providing a versatile vegetable oil with applications spanning food, cosmetics, and bio-fuels [14]. Originating in West Africa, palm oil cultivation has expanded to tropical regions worldwide, primarily Indonesia and Malaysia, which are now the leading producers [15].While palm oil offers economic benefits, its production has raised environmental and ethical concerns due to deforestation, habitat destruction, and labour practicesthereby targeting sustainable initiatives and certificationsto address these issues. Furthermore,the oil palm industry relies on machines like sterilizers, cranes, strippers, digesters, centrifuges, oil dryers, conveyors and mechanical presseswhich entails different segments of production processesas presented in Table 2 for efficient palm oil extraction [16-18]. According to Ahmadi and Rahim [4], these machines can face issues such as wear and tear, electrical or mechanical problems, steam supply, or hydraulic faults, causing costly production disruptions. To address these challenges, proactive maintenance and root cause analysis (RCA) techniques are crucial for enhancing machine reliability and performance, ensuring the industry's efficient and sustainable operation.

In the quest to enhance oil palm mill efficiency, modern techniques are leveraged, including the application of lean manufacturing tools, such as the fishbone diagram, identification of eight deadly wastes, and the calculation of takt-time, which played a pivotal role in streamlining operations [19]. In addition, a quantitative model of the supply chain was applied, utilizing critical path method (network analysis) to determine the optimal route [20].The combination of these advanced tools empowers researchers and industry practitioners to pinpoint the critical areas demanding maintenance and process optimization, ensuring smooth oil palm production.

Some exceptional industrial optimization studies have been conducted by applying lean manufacturing and quantitative supply chain model, such as Ota et al.,[19] examined how lean manufacturing techniques optimize batch production and operational management in an aluminum company. By employing methods like value stream mapping and Kaizen, the study identifies and addresses various waste types affecting performance. Results show significant improvements, including reduced production time and enhanced efficiency. The study underscores the importance of lean practices in mitigating defects, inventory issues, and transportation delays, offering valuable insights for industry leaders to improve performance.

Ezeaku et al.,[20] utilized supply chain risk analysis for a water tank manufacturing company in Aba, Abia state, Nigeria, focusing on optimizing supply flow and reducing costs. Through various quantitative models and analyses, including route time estimation and cost-related risk assessment, the study identifies the most time-efficient route (PATH 6) and compares logistic choices for cost-effectiveness. The developed decision tree model highlights vulnerabilities and proposes mitigation strategies, emphasizing the need for comprehensive risk management in supply chain decisions. The study recommends practical measures like partnering with distributors and leasing warehouses to optimize supply chain management and mitigate risks effectively.

David et al.,[18] addressed the challenge of low productive efficiency and frequent machine breakdowns in manufacturing industries, emphasizing the importance of equipment maintenance. It presents a strategic process improvement plan using Lean Six Sigma (LSS) methodology, particularly the DMAIC approach, to enhance production processes. Through qualitative and quantitative analyses, including surveys and structured questionnaires, the study demonstrates significant improvements, with an average increase of 68% contributing to 79% productive efficiency. Statistical analysis identifies defects and proposes solutions, leading to a substantial enhancement in quality (44.3%) and efficiency (29.9%), as well as a 57.4% improvement in overall equipment effectiveness (OEE). The research underscores LSS as a sustainable solution for reducing defects, optimizing resources, and driving continuous improvement in manufacturing processes, ultimately enhancing machine performance and customer satisfaction.

Cai et al.,[17]investigated the operational challenges faced by fashion retail supply chains with used apparel collection (UAC) programs. It begins with a basic model, examining how fashion brands promote UAC and classify collected apparel for charity or remanufacturing. Optimal promotion efforts are analytically derived, revealing coordination challenges in traditional supply chain contracts. An effort cost sharing (ECS) contract is proposed to address this, proving effective profit coordination. Extended models, including consumer coupon offerings and consumer heterogeneity, are explored to validate the findings. The study provides valuable insights for practitioners on optimizing UAC programs while contributing to academic literature in supply chain management.

The existing literature provides valuable insights into the application of lean manufacturing and supply chain models for optimizing manufacturing and supply chain operations in various industries. However, most studies focus on theoretical aspects and empirical applications without addressing the specific challenges encountered by palm oil mill companies, particularly regarding machine failures and management deficiencies. By applying lean manufacturing and supply chain model tools, this study not only identified shortcomings in the management system and proposed remedies but also optimized takt-time to reduce excess time waste in the palm oil production process, addressing critical components of the industry's operations.

2. MATERIALS AND METHODs

2.1 Materials

The materials used in this research includes:

i. Oral interviews conducted with select staff members.
ii. Company journals, magazines, bulletins, and data storage systems.
iii. Resources obtained from libraries.
iv. Online research conducted via the internet.
v. Maintenance log sheets documenting machine breakdowns.
vi. Utilization of Microsoft Excel software for data analysis and modeling.

2.2 Methods

For effective research planning and execution of the study, Fig. 1 outlined flowchart illustrating the key steps undertaken in the optimization of palm oil production through the strategic deployment of lean manufacturing tools and supply chain analysis.

2.2.1 Brief description and problem identification in the case study company System

The case study conducted at palm oil mill in Nigeria, established in 1991, underscores its pivotal role in the palm oil industry, contributing to

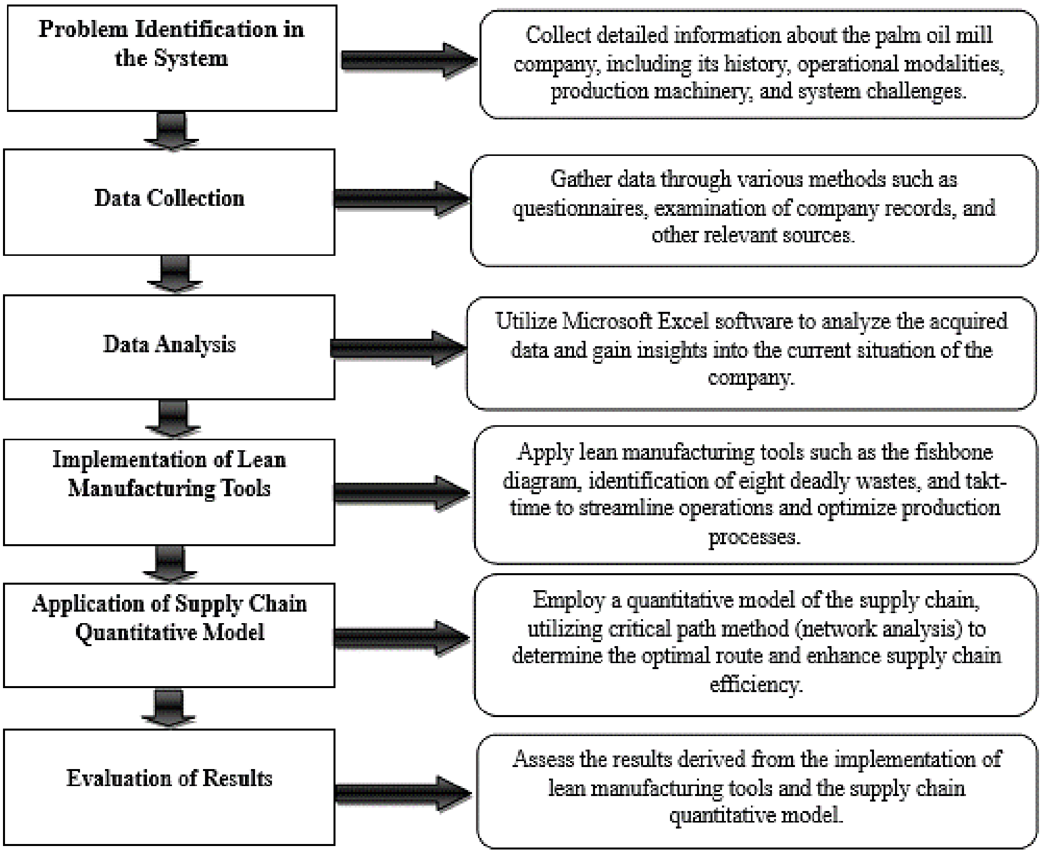

Fig. 1. Schematic flowchart of the research methodology

economic development, employment, and community welfare. The company has demonstrated consistent growth in palm oil production and sales, achieving commendable results in fresh fruit bunches (FFBs) harvesting, processing, and palm oil extraction.

However, a detailed analysis of its production records reveals a decline in system extraction rate and a fluctuating trend in production volumes over the years (1991 – 2016). This decline is majorly observed in production and supply system of the company which highlights potential operational inefficiencies and challenges facing the company. Despite its commitment to sustainability and responsible business practices, the palm oil company faces hurdles in maximizing its production potential and meeting customer demands. Therefore, the investigation aims to identify and address these challenges through the deployment of lean manufacturing and supply chain mechanism techniques, focusing on optimizing production processes and enhancing operational efficiency in the palm oil mill.

2.2.2 Data collection

The data collection process for the study at the palm oil mill company involved a comprehensive approach, utilizing structured questionnaires, company bulletins, oral literatures, and interviews with employees across various departments. A total of 100 questionnaires were distributed among the 398 employees, with 81 returned and analyzed, whereas Table 3 presents the annual report of production and target of the company.

Other data used in this study was sourced from different departments, including records, production, maintenance, and supply management, to gather information on FFB harvest, sales, processing, machine specifications, maintenance schedules, and supply chain routes. Additionally, production and managerial staff were queried about their knowledge and application of lean manufacturing techniques.

Table 3. Yearly production and sales record of the case study company (1991 – 2016)

Year	FFB Harvested (Tons)	FFB Sold (Tons)	FFB Processed (Tons)	Palm Oil Produced (Tons)	System Extraction Rate (%)	Target Extraction Rate (%)
1991	8,333.34	1,234.62	7,098.67	1,300	18.00	20
1992	5,972.22	2,256.23	3,715.99	1,875	18.00	20
1993	8,518.34	2,676.28	5,842.06	1,964	19.10	20
1994	6,108.23	2,367.23	3,741.00	1,980	18.50	20
1995	6,332.54	3,122.12	3,210.42	1,100	18.98	20
1996	3,492.41	1,283.61	2,208.80	1,208	18.63	20
1997	4,334.67	2,103.95	2,230.72	900	13.00	20
1998	3,571.23	1,855.85	1,715.38	1,033	13.00	20
1999	5,264.74	3,803.21	1,461.53	1,100	13.00	20
2000	2,153.16	1,234.65	918.51	984	13.50	20
2001	3,471.94	1,740.40	1,731.54	1,150	12.85	20
2002	5,148.35	2,351.48	2,796.87	950	12.80	20
2003	8,375.63	3,875.63	4,500.00	980	12.00	20
2004	9,614	3,693.17	5,947.83	1,947.47	16.00	20
2005	7,952	3,851.57	4,100.43	1,925.08	19.52	20
2006	4,615	2,106.88	2,508.12	1,600.21	14.85	20
2007	3,288.87	1,384.72	1,904.13	922	13.37	20
2008	6,878.10	2,282.46	4,595.64	1,678.50	9.53	20
2009	4,804.70	2,894.15	1,910.55	957.46	9.21	20
2010	5,641.20	3,332.40	2,308.80	997.79	9.00	20
2011	3,863.51	2,943.20	920.31	662.82	9.00	20
2012	1,349.30	900	449.30	141	8.85	20
2013	4,641.25	3,341.43	1,299.82	816.68	8.90	20
2014	3,115.81	2,341.00	774.81	409.95	8.90	20
2015	3,948.11	2,546.92	1,401.19	641.40	8.95	20
2016	4,958.32	3,958.32	1,000.00	634.67	7.75	20

Source: Palm Oil Mill Production & Sales Record Dept. (2019)

2.2.3 Data analysis

The collected data, spanning from 1991 to 2016, was meticulously analyzed using Excel software, focusing on production metrics, machine downtimes, maintenance costs, supply chain routes, and staff expertise. The analysis revealed trends in FFB harvesting, processing, and palm oil production, as depicted in Table 3, highlighting fluctuations in system extraction rates and production volumes over the years. This comprehensive data collection process provided valuable insights into the operational dynamics and challenges faced by the company, setting the foundation for further analysis and optimization efforts.

2.2.4 Implementation of lean manufacturing tools

2.2.4.1 Fishbone (Ishikawa) diagram

In alignment with the lean manufacturing methodology, this study adopts a systematic approach to analyze and enhance the operations at the case study company. A key tool in the methodological arsenal is the Fishbone (Ishikawa) diagram, a powerful visual technique designed to uncover the root causes of inefficiencies and waste within the palm oil processing system [18]. Fig. 2 presents the fishbone diagram applied to get to the root of the company inefficient productivity problem.

This diagrammatic approach resented in Fig. 2 enables a comprehensive investigation into the various factors contributing to operational challenges, making it an invaluable instrument for pinpointing areas of improvement and facilitating data-driven decision-making. By incorporating the Fishbone diagram into the lean methodology, we aim to identify and address the underlying causes of issues within the company processes, ultimately driving productivity improvements and enhancing the sustainability of the palm oil production operations.

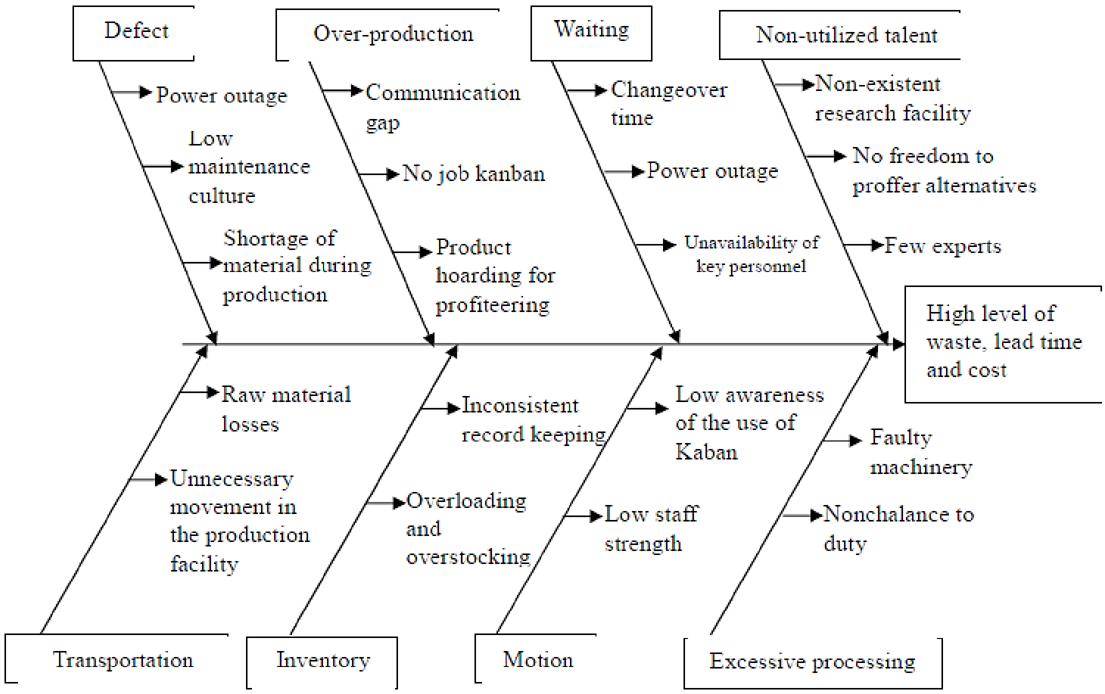

Fig. 2. Developed Ishikawa diagram for the system

2.2.4.2 Eight deadly wastes

The eight deadly wastes, a fundamental concept in lean manufacturing, identifies inefficiencies within processes to eliminate them. In a palm oil mill context, these wastes encompass defects, overproduction, waiting, underutilized talent, transportation inefficiencies, excess inventory, motion waste, and extra processing.Defects refer to errors in the production process, leading to rework or spoilage. Overproduction involves producing more than necessary, resulting in excess inventory. Waiting occurs due to equipment breakdowns or inefficient scheduling. Non-utilized talent reflects the underutilization of workforce capabilities. Transportation inefficiencies involve unnecessary movement of palm oil or fruit bunches. Excess inventory ties up capital and warehouse space, while motion waste and extra processing involve unnecessary actions or redundant steps. Addressing these wastes involves identifying and analyzing them, implementing measures such as equipment optimization and quality control to enhance efficiency and productivity in the palm oil mill [17-18].

2.2.4.3 Takt-time model

Lean manufacturing encourages precise work flow and consciously eliminating waste causing activity [19]. It is then imperative to make judicious use of time available for work to achieve high productivity. Therefore, leveling the production quantity to a definite time (preferably a given number of seconds or minutes) based on the customer demand should be a prerequisite to achieving a structured clear-cut work flow pattern for each product (available work time/customer demand). This accurate timing describes takt time and is evaluated using the following information which involved available time for manufacturing and average customer requirement within a specific period of time.

Takt time = TK can be expressed mathematically as follows

$$TK = \frac{A_t}{c} \tag{1}$$

$$A_t = T_s - B \tag{2}$$

$$C = \frac{(D/n)}{s} \tag{3}$$

Where $A_t(secs/shift)$ is the time available; $c(units/shift)$ represents the customer requirement per shift; $TK,\ T_s,\ B(secs)$ represents the Takt time, the time per shift and time appropriated for break respectively; $D(units)$ denotes the total customer demand per day or week or month; $n(days)$ is the number of working days per week or month and $s(-)$ is the number of shifts.Adopting takt time will give reliable information to aid organization of machines, labour hours required for a particular process and other criteria's that influences effective production. This approach is applicable to single product and/or multiple product manufacturing to eliminate low efficiency associated with the existence of wastages in the system.

2.2.5 Application of quantitative supply chain model

The critical path analysis technique was applied to identify the essential path within the supply chain that requires optimization to minimize or eliminate risks in the context of the palm oil mill. The efficiency of the palm oil mill is intricately tied to its supply chain, which encompasses various routes and a diversified network [20]. While this diversification may appear efficient, it can significantly impact the company's operations either positively or negatively. Table 4 outlines the supply chain paths and the corresponding time required for the product to travel from the finished production point to its final destination in the main market.

Table 5 illustrates the time in hours required for the palm oil tanks to reach various destinations before reaching the final consumers. In this representation, A represents the Factory, B is Warehouse 1 (W1), C is Warehouse 2 (W2), D is Supplier 1 (S1), E is Supplier 2 (S2), F is Supplier 3 (S3), G is Retail Store 1, H is Retail Store 2, and I is the Market.

Table 5 displays the critical path analysis of the supply chain, revealing the minimum time required for the tanks to transition from one path to another. It also delineates the earliest finish time essential for the movement between different segments of the supply chain. The term "float" denotes the additional time available for transitioning from one destination to another. Paths with zero (0) floats warrant careful attention to avoid disruptions in the supply chain process or encountering risks.

Table 4. Supply paths and time taken to get to the expected point

S/N	Supply Path	Duration of Each Point (Hrs.)
1	A – B	4
2	A – C	5
3	B – D	3
4	B – E	2
5	C – E	4
6	C – F	1
7	D – G	5
8	E – G	3
9	E – H	4
10	F – H	1
11	G – I	2
12	H – I	5

Table 5. The critical path analysis table

Activities	Duration (D)	EST	EFT	(EST+D)	LST (LFT-D)	LFT	Total Float (LFT-EFT)	Free Float	Indep. Float
A – B	4	0	4	4	0	4	0	0	0
A – C	5	0	5	5	0	11	6	0	0
B – D	3	4	7	7	4	7	0	0	0
B – E	2	4	6	6	4	10	4	2	0
C – E	4	5	9	9	5	13	4	2	0
C – F	1	5	6	6	5	13	7	5	0
D – G	5	7	12	12	7	12	0	0	0
E – G	3	6	9	9	6	15	6	4	4
E – H	4	6	10	10	6	14	4	0	0
F – H	1	6	7	7	6	13	6	5	5
G – I	2	12	14	14	12	14	0	0	0

Table 6. Pathduration analysis for optimal product movement in palm oil mill company

Path	Path Stations	Duration Calculation (hrs.)
1	A > B > D > G > I	4 + 3 + 5 + 2 = 14
2	A > B > E > G > I	4 + 2 + 3 + 2 = 11
3	A > B > E > H > I	4 + 2 + 4 + 5 = 15
4	A > C > F > H > I	5 + 1 + 1 + 5 = 12

As shown in Table 6 which indicates that four path is possible to see the product to its last destination. From the observation it is shown that it takes the palm oil mill company more time (14)hours to move its plastic tank through path 1, which is the time possible in the model while it takes 11 hours through path 2.

2.2.6 Evaluation of results

From 2018 to 2022, a detailed analysis of the case study palm oil mill, was conducted, comparing it with the preceding 2012-2016 period to uncover persistent challenges. Strategic management tools were then employed to boost productivity, including lean manufacturing principles like mitigating the eight deadly wastes, establishing takt-time, and utilizing fishbone diagrams. Additionally, a quantitative supply chain management model was introduced to optimize operational processes. The validation process aimed to assess the effectiveness of these tools in driving positive change and enhancing productivity. Challenges impacting productivity encompass financial constraints, market dynamics, machine failures, management issues, supply chain disruptions, and more. By applying lean manufacturing and a supply chain model, the study targets issues like machine failures, downtimes, maintenance costs, and supply chain inefficiencies, aiming to optimize operations and improve overall performance of the system.

3. RESULTS AND DISCUSSION

This phase presents and discusses variousresults obtained after utilization of the management tools (lean manufacturing and quantitative supply chain model) adopted to optimize the palm oil mill company. The result presented includes the survey response from the staff on utilizing some the lean manufacturing tool, improved percentage in maintenance cost, supply cost, machine downtime, and time of the production, the validation of these result entails before (2012 – 2016) and after (2018 – 2017) application of the management tools.

3.1 The Situation of the Company before Implementation of the Management Tools

Fig. 3 presents the frequency of using various lean management tools within the organization. Notably, Heijunka and Takt-Time shows the highest consistency in application, with 70% and 74% "Always" responses, respectively. However, it's concerning that a significant portion of respondents indicated "Never" or "Rarely" using essential tools like VSM, Kanban, and Jidoka, suggesting potential gaps in implementing these methodologies. The variation in responses underscores the need for a more comprehensive and consistent adoption of lean practices across the organization for optimal efficiency and continuous improvement.

Fig. 4 presents the current situation of the company's production target extraction rate and system extraction rate from 1991 to 2016 before the implementation of management tools. The bar graph illustrates the target extraction rate of 20% and the actual system extraction rate from 1991 to 2016, showing significant percentage differences over the years. In the early 1990s, the system extraction rate fluctuated between 15% and 20%, closely aligning with the target. However, from 1998 to 2008, the system rate consistently dropped to around 10-15%, indicating a 5-10% shortfall. The period from 2009 to 2016 shows a more pronounced gap, with extraction rates frequently below 10%, resulting in a 10-15% discrepancy from the target. Notably, 2004 saw the system extraction rate peak at 20%, matching the target, while the lowest rates were observed around 2005 and 2016.

3.2 Evaluation of the Utilized Lean Manufacturing into the System

Table 7 presents the calculated takt time which is the maximum time allowed for producing one unit to meet customer demand of the company before and after implementation of the management tools. The calculated takt time for the earlier production process is determined as 3168 seconds, considering time per shift, breaks, and customer demand. The improved production process reflects a reduced Takt time of 2304 seconds, achieved by optimizing the time available, incorporating additional value-adding activities, and maintaining the same customer requirement per shift. This analysis showcases a significant enhancement in efficiency, highlighting the potential for streamlining operations and meeting customer demand more effectively in the improved production scenario which agrees with Ota et al.,[19] research result on aluminium sheet industry.

Fig. 5 depict a comparison of key performance indicators related to the oil palm processing industry over the years. In the initial period (2012-2016), there was a fluctuating trend in FFB harvested, FFB sold, and palm oil produced. However, the target extraction rate remained relatively consistent at 20%, and the system extraction rate varied. In the subsequent years (2018-2022), there is a noticeable shift in performance metrics. FFB harvested and processed increased significantly, leading to higher palm oil production. The target extraction rate is consistent at 20%, but the system extraction rate shows variations, indicating potential operational adjustments. The data suggests a positive trend in achieving extraction goals, with notable improvements in FFB utilization and palm oil output from 2018 onwards which streamlines with the research result by Ahmadiand Rahim [4].

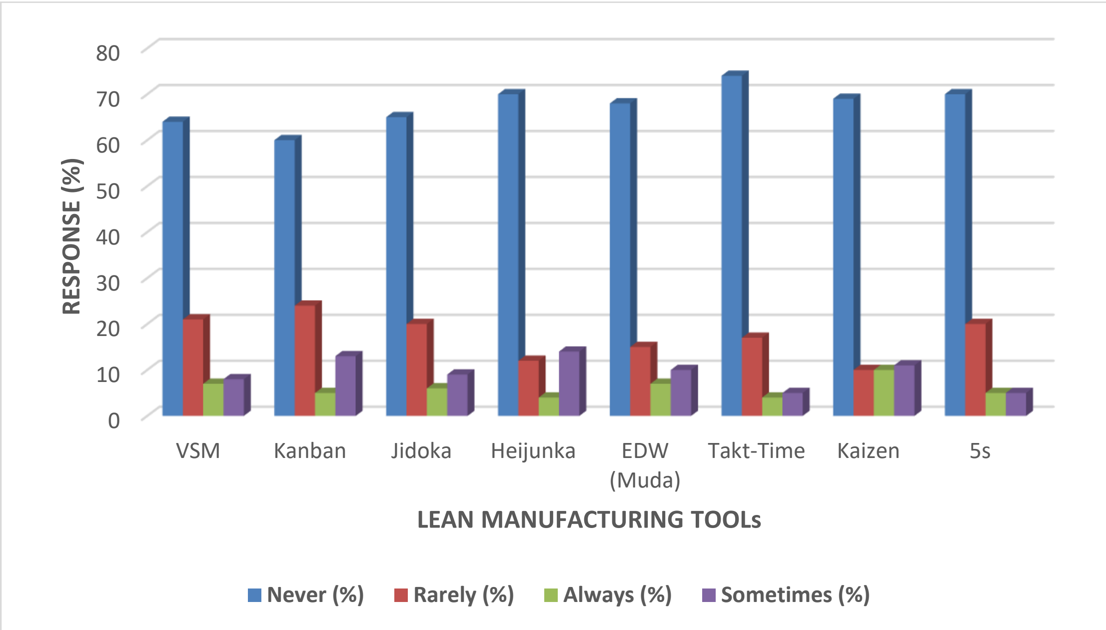

Fig. 3. Staff responses and survey findings about lean manufacturing

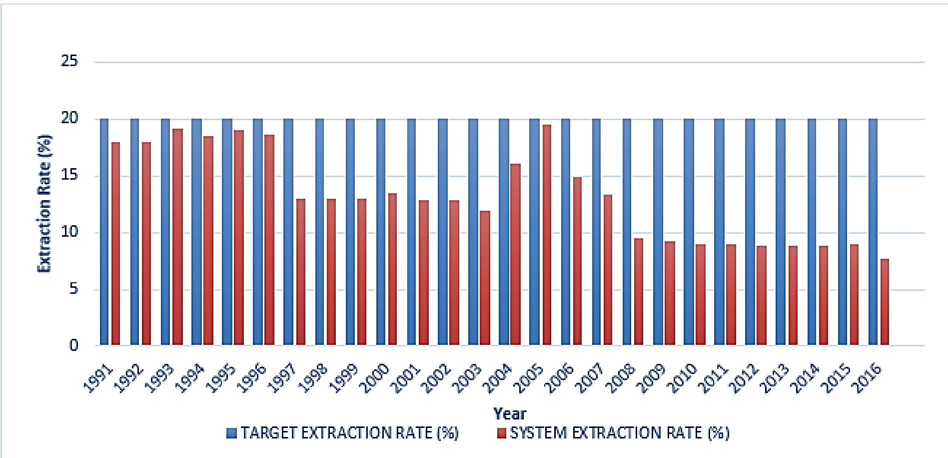

Fig. 4. Product target and archived rate (1991 – 2016)

Table 7. Calculated takt time of the production process of the palm oil mill

Item	Symbol	Units	Value
Time before implementation of the management tools			
Time per shift	Ts	$secs$	45163
Break	B	$secs$	3762
Time available	At	$secs/shift$	41422.2
Total customer demand	D	$units$	627
Number of working days	n	$days$	25
Number of shifts	s	-	2
Customer requirement per shift	$\mathbb{C}$	$units/shift$	13.12
Additional value-adding activity	Vad	$secs$	0
Takt time	$\boldsymbol{TK}$	$\boldsymbol{secs}$	**3157**
Time after implementation of the management tools			
Time per shift	Ts	$secs$	45163.8
Break	B	$secs$	3762
Time available	At	$secs/shift$	30370.8
Total customer demand	D	$units$	627
Number of working days	n	$days$	25
Number of shifts	s	-	2
Customer requirement per shift	$\mathbb{C}$	$units/shift$	13.12
Additional value-adding activity	Vad	$secs$	188
Takt time	$\boldsymbol{TK}$	$\boldsymbol{secs}$	**2314**

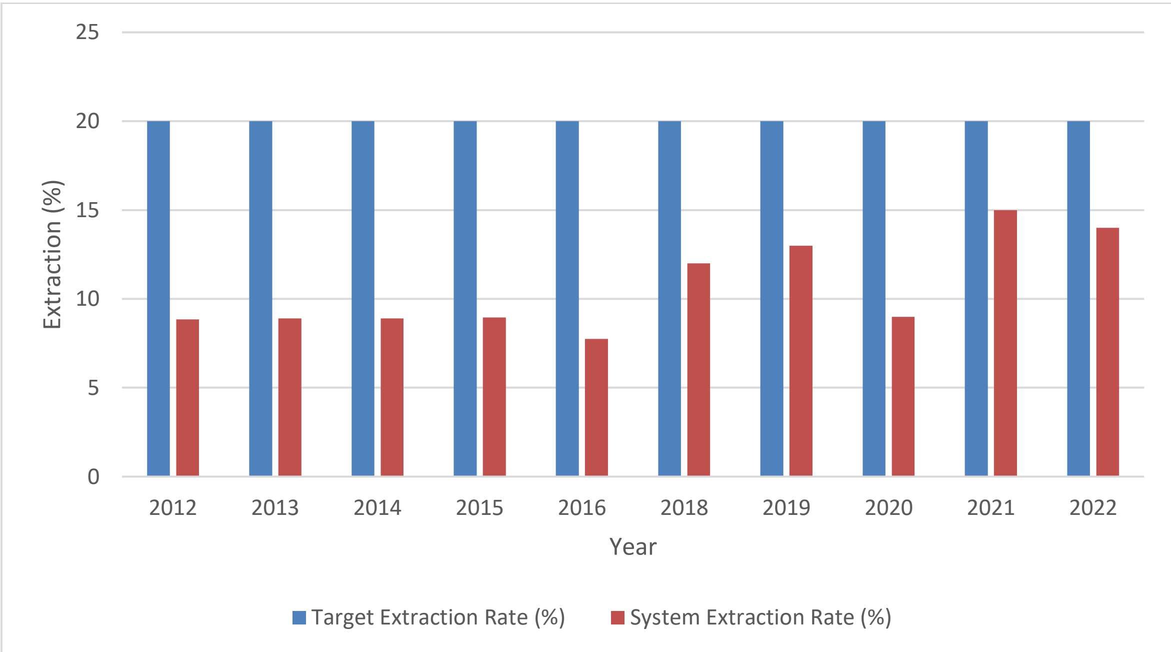

Fig. 5. Comparison of performance metrics and extraction rates

Fig. 6 presents the comparison of the annual machine downtime summary from 2012 – 2022, after utilizing fishbone diagram and eight deadly waste lean manufacturing tool. The trend indicated that the machine downtime reduced drastically from 2018 to 2022 compare to 2012 to 2016 maybe due to the application of lean manufacturing technique especially on the area of employing corrective, preventive, and time schedules against the regular problem involved in the production machine. The lowest downtime was observed in 2020, due to COVID-19 pandemic period were production declined, this result agrees to the study by David et al., [18] on Integrating machine availability and preventive maintenance to improve productive efficiency in a manufacturing industry.

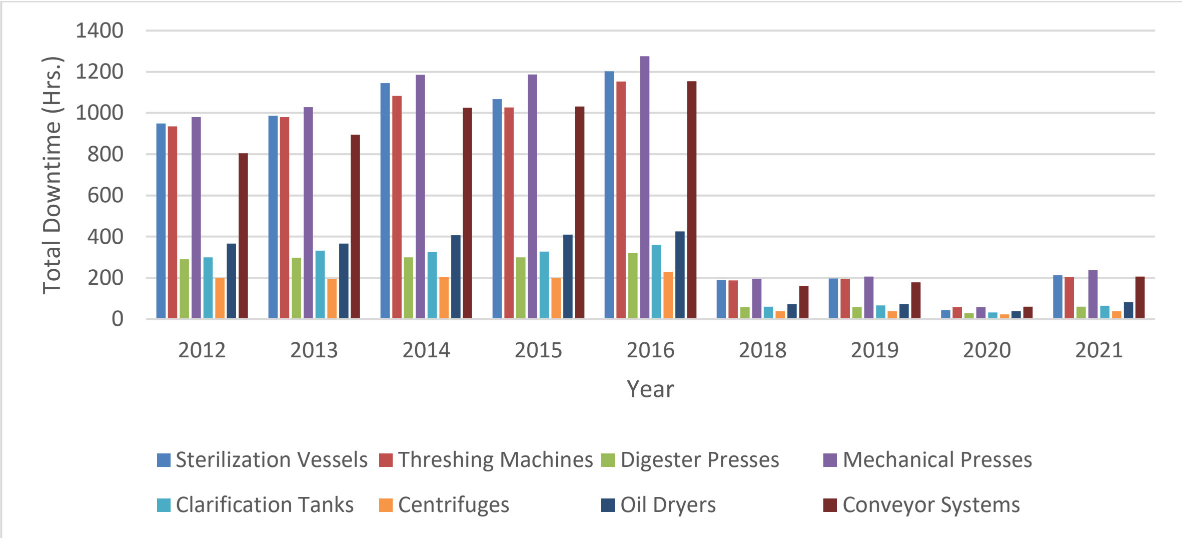

Fig. 6. Comparison of the machine downtime summary (2012-2022)

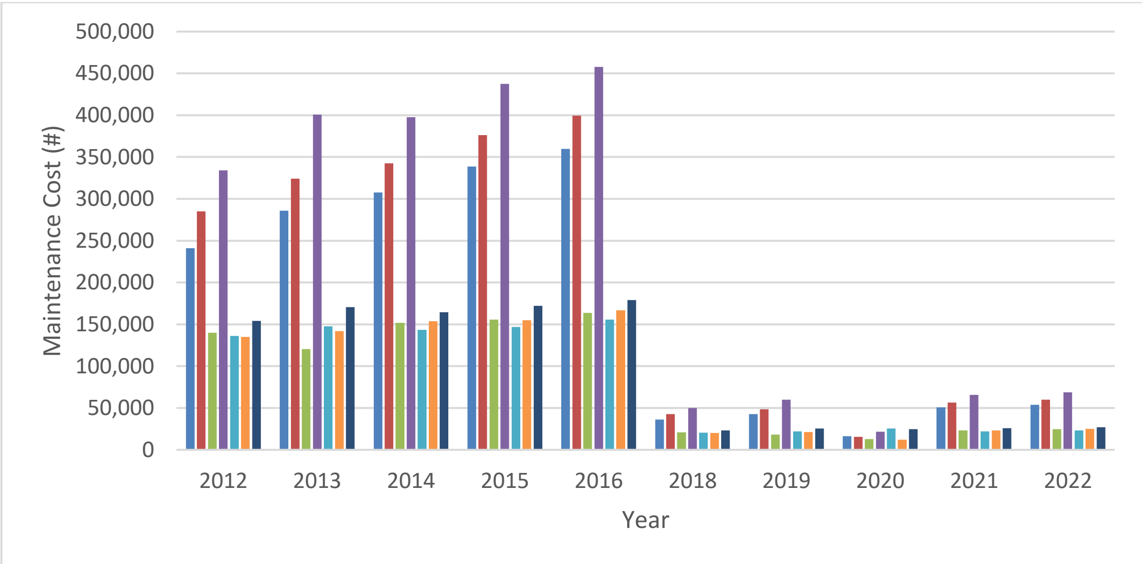

Fig. 7. Comparison of the cost of maintenance and repair of each machine

Fig. 7 presents the comparison summary of the palm oil mill cost of maintenance and repair of each machine from 2012 – 2022 before and after implementation of management tool. The trend indicated that the cost of maintenance and repair reduced drastically from 2018 to 2022 compared to 2012 to 2016 due to the application of lean manufacturing techniques especially on the area of corrective, preventive and time schedules. From the trend, it was also observed that the year 2020 was the lowest of the cost of maintenance and repair, due to COVID-19 pandemic, this result agrees with the result from Ota et al.,[19] and David et al.,[18].

3.3 Evaluation of the Utilized Quantitative Supply Chain Model into the System

Fig. 8 presents the comparison of the annual cost of supply of the product to the major. The trend indicated that the supply cost reduced drastically from 2018 to 2022 compare to 2012 to 2016 thereby the earlier years indicated recorded cost trends above the budgeted cost, while in 2018 - 2022 the trend of recorded cost after supply went below the budgeted cost, due to the application of supply chain quantitative model technique which detected best path (Path 2) to supply the dealers and application of lean manufacturing tools that may have detected illegal or unnecessary tasks during the supply. This result agrees with the model developed by Ezeaku et al., [20] on applying quantitative models for supply chain risk analysis in water tank manufacturing which the case study is a factory in Aba, Nigeria.

Fig. 9 illustrates the provides a comprehensive overview of the company production and processing metrics from before (1991–2016) and after (2018 – 2022) the application of the management tools.The result includes data from the fresh fruit bunches (FFB) harvested, FFB sold, FFB processed, palm oil produced, target extraction rate and system extraction rate. The data serves as a valuable resource for understanding the company's historical performance and its adherence to extraction rate targets. The result illustrated result streamlines with Ota et al., [19] and Ezeaku et al.,[20] industrial research result.

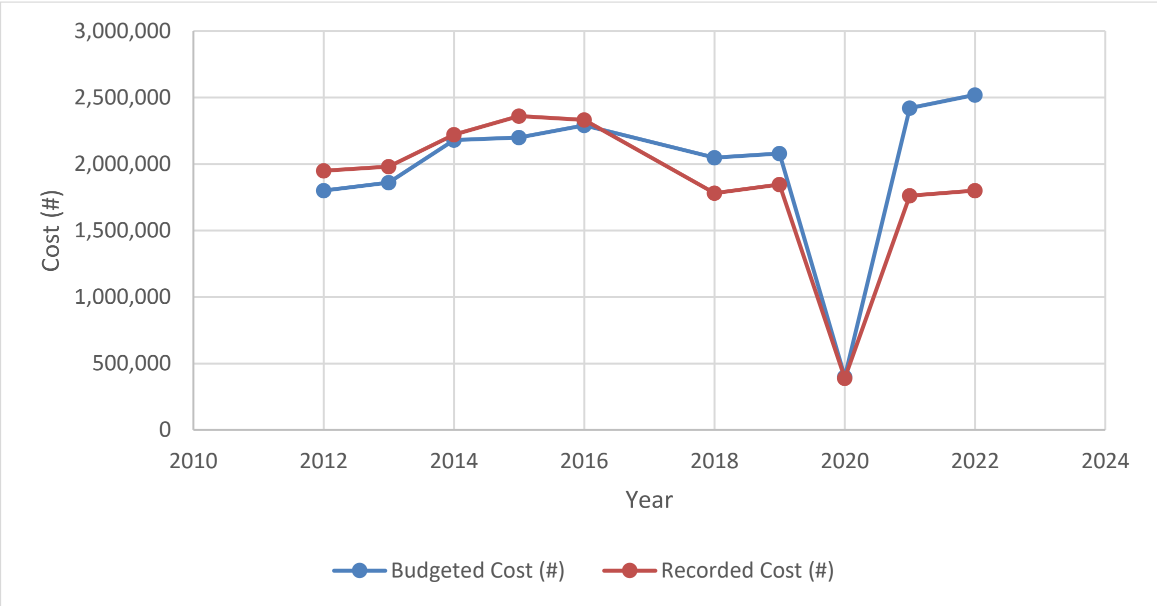

Fig. 8. Comparison of the supply cost to the major dealers

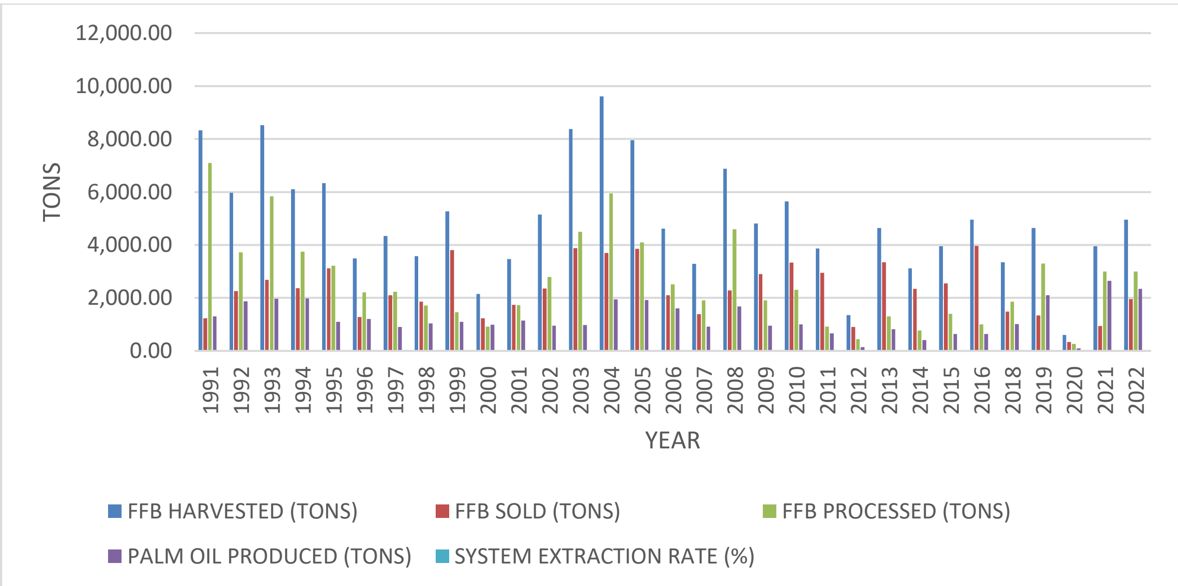

Fig. 9. Yearly production and sales record before and after utilizing the management tool

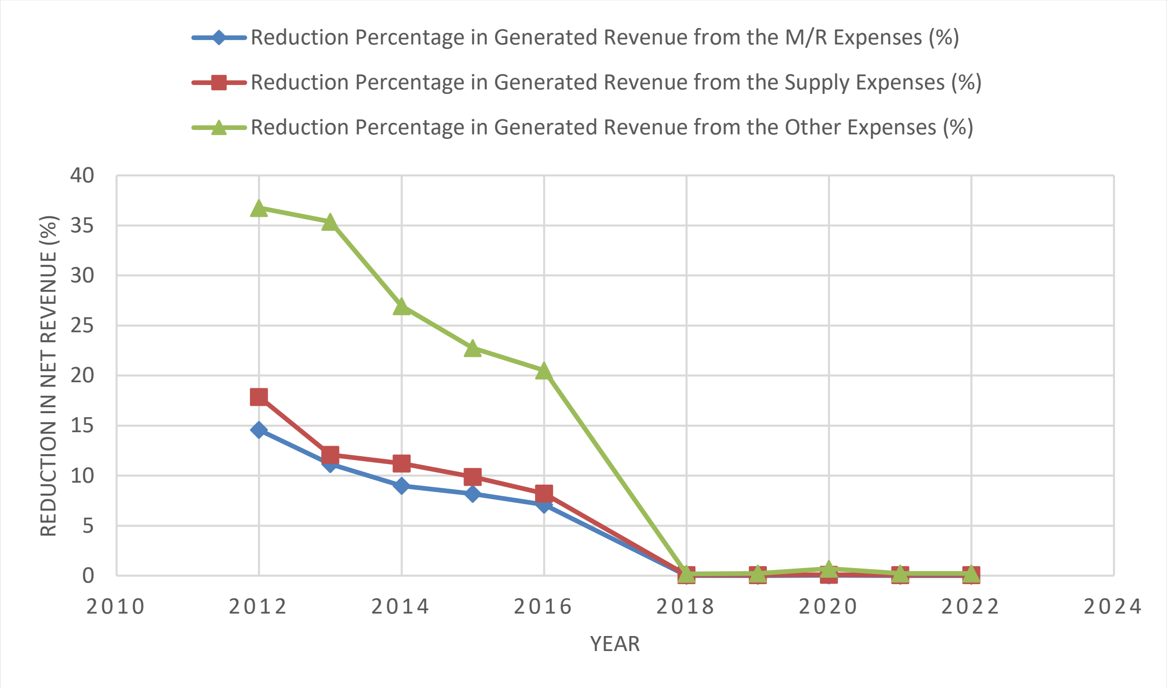

Fig. 10. Evaluation of Cost Optimization Strategies through Lean Manufacturing and Supply Chain Models (2012-2022)

The research spanning from 2012 to 2016 and from 2018 to 2022 evaluated the effectiveness of cost optimization strategies through lean manufacturing and supply chain quantitative models. However, after the implementation of lean manufacturing and supply chain quantitative models from 2018 to 2022, the reduction percentages experienced slight fluctuations but generally remained lower compared to the pre-implementation period. As presented in Fig. 10, in 2022, reduction percentages in generated revenue from machine repair expenses were 0.993%, from supply expenses were 5.72%, and from other expenses were 23.37%. These findings underscore the effectiveness of the applied strategies in optimizing costs and improving overall revenue generation.

4. CONCLUSION

The deployment of lean manufacturing in the palm oil mill company aimed at maximizing yield proved highly effective. The company, previously facing declining production and decreased customer satisfaction, experienced substantial improvements following the implementation of lean strategies. Comprehensive data collection and analysis using Microsoft Excel facilitated a deep understanding of the operational challenges and opportunities for optimization. Lean manufacturing tools, including the fishbone diagram, identification of the eight deadly wastes, and takt-time, streamlined operations, while the supply chain quantitative model identified the optimal supply route. The results were impressive: average oil palm extraction increased from 8.67% to 30.52%, and machine downtimes significantly decreased from 5,498.6 hours to 2,472.4 hours annually. These changes led to a dramatic reduction in machine maintenance costs and supply chain expenses, boosting net revenue by 71.99%. This comprehensive approach not only addressed production challenges but also significantly improved the company’s financial performance. The strategic deployment of lean manufacturing emerged as a catalyst for sustainable growth and enhanced operational efficiency.

5. RECOMMENDATIONS

Based on the findings and conclusion of the study, the following recommendations were made:

i. Explore how emerging technologies like artificial intelligence, IoT, and automation can be integrated into palm oil mills to enhance efficiency, reduce manual labour, and optimize overall operation.

ii. Applications of advanced data analytics and predictive maintenance models to anticipate machinery failures, optimize maintenance schedules, and minimizes downtime in palm oil milling processes.

iii. Explore innovative and sustainable energy solutions, such as solar energy to power palm oil mills, reducing the environmental impact and operational costs

iv. Develop methods to measure and reduce the carbon footprint of palm oil production, incorporating sustainable practices to minimize environmental impact and align with global sustainability goal.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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