

**OPTIMIZATION OF ALUMINIUM SHEET PRODUCTION IN  
A DISTRESSED ECONOMY**

**BY**

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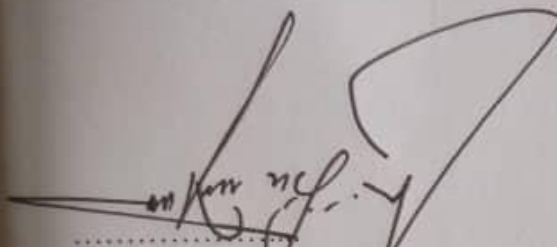
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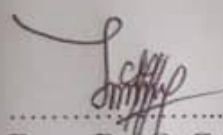
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## CERTIFICATION

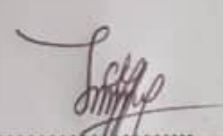
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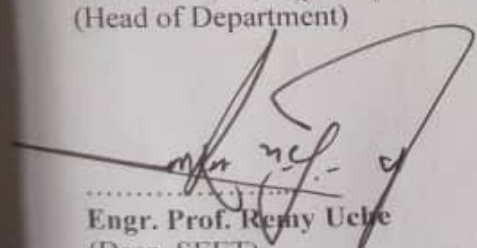
  
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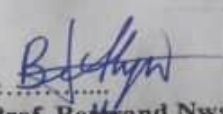
  
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## **DEDICATION**

This work is dedicated to God almighty for all His grace, mercy and faithfulness.

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## ABSTRACT

This research deals with the optimization of aluminum sheet production in a distressed economy. The aluminum roofing sheet industry plays a pivotal role in the construction sector due to the inherent advantages of aluminum roofing sheets including corrosion resistance, lightweight properties and recyclability. Operational inefficiency results in higher production costs and operational delays. The methods applied in this study includes data collection through questionnaires and the company record books. Data analysis using Excel and Python were used to identify trends and pattern in machine failure and this helped in understanding the factors contributing to decline in productivity. Strategic maintenance initiative including Lean manufacturing tools like Heijunka and Takt Time were used to facilitate increase in production while application of predictive maintenance through regression model were used to reduced average machine downtime thereby increasing the operational efficiency. From the result obtained, the Analysis of production data from 2017 to 2021 shows operational inefficiencies and external disruptions, such as machine downtime and pandemic-related constraints, which collectively contributed to a 28.8% decline in total production and a 20% reduction in production targets over the period. The application of predictive maintenance through regression models demonstrated a substantial improvement in operational efficiency, notably reducing average machine downtime by 55.3% from 1,316.67 hours in 2021 to 588.34 hours in 2023. In addition, strategic maintenance initiatives, including lean manufacturing tools like Heijunka and Takt Time, facilitated a 56.2% increase in total production from 3,170 tons to 4,950 tons between 2017-2021 and 2022-2023 periods, respectively. This enhancement not only optimized production schedules but also aligned production rates more closely with market demand, resulting in a 30.4% improvement in net revenue generation after expenses. Cost management strategies further stabilized machine maintenance costs around the benchmark figure of ₦6,000,000 in 2022-2023, showcasing effective financial control amid economic uncertainties.

**Keywords:** *Distress Economy, Regression model, Lean Manufacturing, Productivity, Optimization.*

# CHAPTER ONE

## INTRODUCTION

### 1.1 Background of Study

The aluminum industry stands as a cornerstone of global manufacturing, serving as the foundation for a myriad of applications. Notably, within this industry, aluminum roofing sheets emerge as a critical component. Renowned for their corrosion resistance, lightweight structure, and recyclability, aluminum roofing sheets play an integral role in the construction sector.

However, the aluminum roofing sheet industry in Nigeria faces a unique set of challenges due to the distressed economic conditions prevailing in the country. Factors such as the post COVID-19 pandemic, Every Monday sit-at-home order by IPOB members in Southeast Nigeria States, instability and high exchange rate (currently 1 USD = 1290 NGN), the high cost of petroleum products, and some other unfriendly governmental policies which could contribute to the distress in the economy. These challenges impact the production and operational management of aluminum roofing sheets, influencing issues like operational inefficiency, production delays, and compromised product quality consistency.

The application of lean manufacturing principles, such as value stream mapping and the elimination of the eight deadly wastes, stands as a viable approach to identify non-value-added activities within the production process. The eight deadly wastes include defects, overproduction, waiting, underutilized talent, transportation, excess inventory, motion waste, and excess processing (Ohno, 1988).

One of the key challenges faced by the aluminum roofing sheet industry is operational inefficiency, which results in a range of wasteful practices. Production delays are commonplace, with the impact being missed delivery deadlines and increased operational

costs. The overarching effect is an inefficient manufacturing process with high production costs (Liker, 2004).

Quality control is another pressing issue. The consistency of product quality can be compromised, leading to the production of substandard roofing sheets that may fail to meet industry standards. Quality management tools and practices represent an integral part of addressing this concern.

Research into the aluminum roofing sheet industry has previously delved into various aspects of production and operational management. Notably, Yusuf, Y., Gunasekaran, A., Adeyeye, E., and Sivayoganathan. K. (2018) conducted a study examining the application of lean manufacturing principles within the industry. Their research highlights significant improvements in productivity stemming from the adoption of lean techniques.

Brown and Smith (2020) explored quality control techniques within the aluminum roofing sheet industry, identifying areas for enhancing product quality consistency. This serves as a vital aspect of the research, given the industry's emphasis on quality standards.

Chen and Wang (2019) addressed production delays in aluminum sheet manufacturing processes. Their study presents strategies for mitigating operational delays, an area crucial for maintaining production efficiency.

Kumar, S., Kopadekar, P., and Navathe, S. (2017) scrutinized the cost structure within the industry, laying the foundation for potential cost reduction strategies. In an industry riddled with production inefficiencies, understanding the cost structure is pivotal in optimizing production and operational management.

This research seeks to build upon and expand these previous studies by comprehensively examining the application of lean manufacturing principles and techniques to address the

challenges faced by the aluminum roofing sheet industry. The utilization of techniques such as Heijunka, takt time, the 5S approach, quality tool management, Kaizen, Kanban, Gemba, and fostering top and bottom-level involvement will be a focal point in this research. By doing so, the study aims to enhance efficiency, quality, and sustainability in the aluminum roofing sheet manufacturing sector.

The aluminum roofing sheet industry is poised for a transformation through the application of lean manufacturing techniques. The ensuing research endeavors to provide solutions to the industry's prevailing challenges by optimizing production and operational management.

## **1.2 Problem Statement**

The aluminum roofing sheet industry plays a pivotal role in the construction sector due to the inherent advantages of aluminum roofing sheets, including corrosion resistance, lightweight properties, and recyclability. However, it confronts a series of pressing challenges, leading to inadequate productivity. These challenges include operational inefficiency, production delays, and compromised product quality consistency.

Operational inefficiency is a recurrent issue within the aluminum roofing sheet industry. The manufacturing process is often marred by non-value-added activities that result in higher production costs and operational delays (Liker, 2004). This inefficiency can exacerbate the effects of the global economic conditions on the industry's competitiveness and sustainability. This inefficiency can exacerbate the effects of the global economic conditions on the industry's competitiveness and sustainability, with specific reference to the challenges faced in Nigeria, such as the impact of COVID-19, sit-at-home orders, and currency devaluation.

Production delays pose a significant problem within the industry. These delays can lead to missed delivery deadlines, increased costs, and lost business opportunities. Chen and Wang

(2019) identified these production delays as a key issue that hampers the industry's ability to meet the growing demand for aluminum roofing sheets.

Another critical challenge is maintaining product quality consistency. The inconsistency in product quality poses a threat to the industry's reputation and customer satisfaction. Brown and Smith (2020) highlighted the importance of quality control techniques within the industry, emphasizing the need for more rigorous quality management.

This research seeks to address the identified problems by focusing on the optimization of production and operational management in the aluminum roofing sheet industry. The application of lean manufacturing techniques and tools, such as value stream mapping, the elimination of the eight deadly wastes, and quality tool management, stands as a promising approach to enhancing productivity and quality within the industry (Womack J.P., Jones D. T., and Ross, D., 1990). Moreover, techniques like Heijunka, takt time, 5S approach, Kaizen, Kanban, Gemba, and fostering top and bottom-level involvement will be integrated into the operational processes to ensure efficiency and sustainability.

The aluminum roofing sheet industry is faced with a series of interrelated challenges that hinder its productivity and competitiveness. By focusing on operational inefficiency, production delays, and product quality consistency, this research aims to optimize production and operational management through the application of lean manufacturing techniques and tools. The outcomes are expected to significantly enhance efficiency, quality, and sustainability within the industry, ensuring its continued growth and contribution to the construction sector.

### **1.3 Objective of Study**

The main objective of this study is optimization of aluminum sheet production in a distressed economy.

Other specific objectives include:

- i. To conduct a thorough observational study of the company's diverse production lines, focusing on different roofing sheet thicknesses, to identify operational inefficiencies and bottlenecks.
- ii. To apply production and revenue optimization (PRO) regression model into the collected data.
- iii. To develop, streamline and compare into the production and managerial system of the company some management skills using lean manufacturing techniques.

### **1.4 Justification of the Study**

The aluminum sheet production industry plays a vital role in construction and infrastructure development. However, it faces persistent challenges related to inadequate production efficiency, waste generation, and suboptimal resource utilization. The global demand for aluminum roofing sheets continues to rise, making it essential to address these inefficiencies and resource allocation problems.

The aluminum sheet manufacturing sector encounters several difficulties. One major challenge is the inefficiency of production processes, which involve multiple stages and variations in sheet thickness. These complexities lead to bottlenecks and inefficiencies, affecting the sector's competitiveness and ability to meet market demands.

In line with global environmental concerns, there is an urgent need to reduce resource consumption and waste. Implementing lean manufacturing principles, including Value Stream Mapping, waste reduction, Heijunka, and more, offers a structured approach to addressing

these issues. This research aims to revolutionize aluminum sheet manufacturing by identifying inefficiencies, streamlining processes, and reducing waste, leading to enhanced productivity and sustainability.

By improving production processes and resource efficiency, this study will benefit manufacturers and align with broader sustainability goals. It has the potential to make the aluminum sheet industry a model of responsible and sustainable manufacturing. Furthermore, it contributes valuable insights into the practical application of lean manufacturing tools, advancing the field of manufacturing science.

### **1.5 Scope of Study**

This research focuses on the optimization of production and operational management in the aluminum sheet manufacturing industry, with a specific emphasis on the production of roofing sheets. The study will be conducted in Anambra State (Onitsha) Eastern part of Nigeria and will encompass three distinct production lines, each dedicated to producing roofing sheets of different thicknesses. It will involve a comprehensive assessment of the production processes, resource allocation, and waste generation across these production lines. The study will also extend to the various operational sectors of the manufacturing plant.

The research aims to identify and address inefficiencies, bottlenecks, and resource utilization issues within the production process while reducing waste and environmental impact. It will involve in-depth data collection, observations, and the implementation of lean manufacturing tools and principles, including Value Stream Mapping, elimination of the eight deadly wastes, Heijunka, takt time optimization, 5S approach, quality tool management, Kaizen, Kanban, Gemba, and top and bottom-level involvement. The goal is to enhance the overall productivity, sustainability, and competitiveness of the aluminum sheet manufacturing industry in of the company.

This study will not only provide insights and recommendations for the specific companies involved but also contribute to the broader understanding of lean manufacturing's applicability in the metal manufacturing sector, thus advancing the field of manufacturing science. It is essential to note that the research will focus solely on the operational and production aspects of the industry and does not encompass marketing, sales, or distribution aspects.

The research period is expected to extend over a year, allowing for thorough data collection, analysis, and implementation. It is anticipated that the findings of this study will have practical implications for the aluminum sheet manufacturing industry in Onitsha City, Anambra State and potentially serve as a model for similar industries globally.

## CHAPTER TWO

### LITERATURE REVIEW

#### 2.1 Conceptual Framework of the Study

The aluminum roofing sheet production industry holds immense significance in various regions worldwide, serving as a cornerstone of the construction and building sector. Renowned for its roofing solutions characterized by corrosion resistance, lightweight properties, and environmental sustainability, this industry is a critical subsector within the broader aluminum industry (Smith, A., Brown, P., and White, L., 2017). The lightweight nature of aluminum roofing sheets contributes to cost savings in terms of labor and transportation, making them ideal for various construction projects (Brown and White, 2019). Moreover, the exceptional recyclability of aluminum roofing sheets aligns with sustainability goals, as aluminum can be recycled multiple times without compromising its quality, further contributing to the industry's eco-friendly image (Roberts and Johnson, 2016).

However, the industry faces a myriad of challenges that impact its productivity and overall competitiveness as presented in table 2.1. Operational inefficiencies often result in production delays, missed delivery deadlines, and increased operational costs, hindering manufacturers' ability to meet market demands (Liker, 2004). Quality consistency is another pressing concern, as variations in product quality can damage the reputation of manufacturers and erode consumer confidence (Gupta and Patel, 2018). Addressing these production-related issues is essential for the industry to maintain its efficiency, reliability, and sustainability (Chen and Wang, 2019).

The aluminum roofing sheet industry is undergoing a transformation through the adoption of lean manufacturing principles and techniques. Lean manufacturing, a systematic approach

focused on identifying and eliminating waste within the production process, is central to optimizing production efficiency and achieving cost savings (Womack J.P., Jones D. T., and Ross, D., 1990). By implementing lean manufacturing tools and practices such as value stream mapping, takt time, and the 5S approach, manufacturers aim to streamline operations and improve productivity (Yusuf, Y., Gunasekaran, A., Adeyeye, E., and Sivayoganathan. K 2018).

As a result, the application of lean manufacturing is providing solutions to the industry's prevailing challenges, offering a pathway to enhance efficiency, quality, and sustainability in the aluminum roofing sheet manufacturing sector. Furthermore, lean manufacturing tools like quality tool management, Kaizen, Kanban, and Gemba are contributing to the industry's competitiveness, while fostering top and bottom-level involvement facilitates the implementation of these techniques across all levels of the organization (Kumar, S., Kopadekar, P., and Navathe, S. 2017).

The aluminum roofing sheet production industry is central to the construction and building sector, offering roofing solutions recognized for their durability and sustainability. Nevertheless, the industry faces significant challenges, including operational inefficiency and quality consistency. The adoption of lean manufacturing principles is pivotal in addressing these issues and transforming the industry's operational management.

## **2.2 Companies that have Collapsed in Nigeria Due to Poor Management and Plan**

Many companies in Nigeria have faced various challenges leading to their closure in recent years. These challenges have had a significant impact on the country's manufacturing sector and its ability to attract investors in various industries. Table 2.1 presents some of the companies that have folded in Nigeria due to poor management that comes inform of internal or external inevitable forces According to *International Center for Investigative Reporting (ICIR)* in business and economy of Nigeria (2022).

**Table 2.1: Collapsed Companies in Nigeria, Year, and Causes**

<b>Company</b>	<b>Year of Closure</b>	<b>Reason (s) for Closure</b>
Errand Products	2019	Foreign exchange scarcity
Phonenix Specialties Nigeria Limited	2018	FX, difficulty in accessing raw materials
Technoflex Company Limited	2017	Rising production cost
Evans Medicals	2017	Bank debt
Kenfrancis Farms Ltd	2017	FX pressure
GlaxoSmithKline Nigeria	2021	High production cost
Iso Glass	2019	FX, raw materials scarcity
Universal Rubber	2019	Policy inconsistency
Multi-Trex Integrated Foods Plc	2015	Bank debt
Standard Biscuits	2020	Poor operating environment
NascoFibre	2020	Poor business environment
UTC Foods	2020	FX, poor operating environment
Deli Foods Limited	2020	Poor operating environment
Rasa Industries	2017	Poor operating environment
Vee Oil	2018	FX scarcity
Triumph Nigeria Limited	2018	Poor operating environment

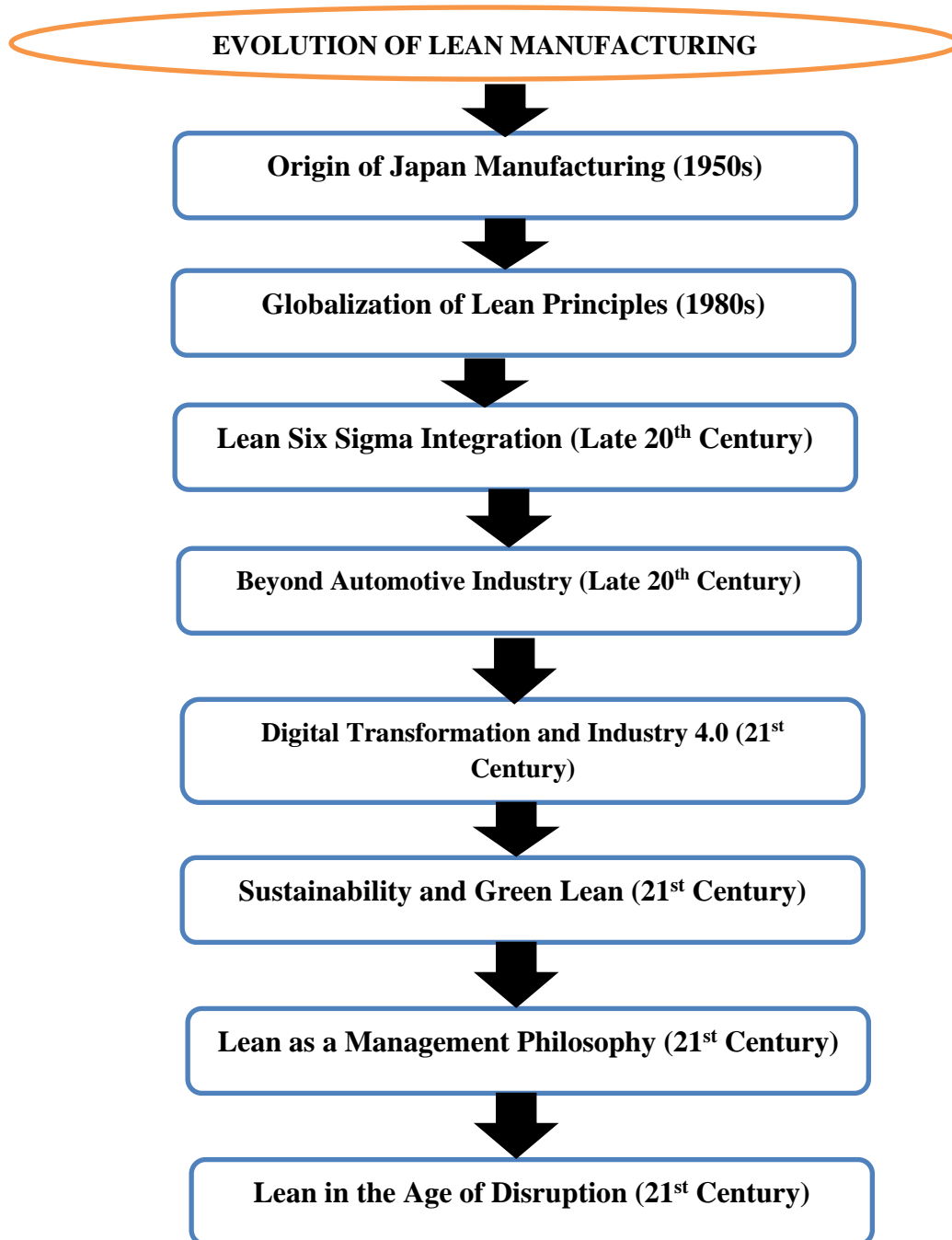
Errand Products Limited, established in 2019, aimed to assemble tricycles and create jobs for young people in Anambra State. However, due to foreign exchange scarcity, the company had to abandon its plans in 2019 (ICIR Investigation). Phonenix Specialties Nigeria Limited had plans to produce drugs and pharmaceutical products in Onitsha in 2018. Still, investors from India left the same year because of difficulties in accessing foreign exchange to import raw materials and challenges in navigating port gridlocks (ICIR Investigation). Technoflex Company Limited, involved in industrial plastic and foam, closed in 2017 due to rising production costs (ICIR Investigation). Kenfrancis Farms Ltd, an agro-processing company, began in 2016 but closed in 2017 because of foreign exchange scarcity and high raw material costs (ICIR Investigation). GlaxoSmithKline Nigeria shut down its drug production plant in the third quarter of 2021 due to ballooning production costs (ICIR Investigation). Universal Rubber in Ibadan closed due to policy inconsistencies, and several companies in Kano, including Rasa Industries, Vee Oil, and Triumph Nigeria Limited, also ceased operations for various reasons (ICIR Investigation). Multi-Trex Integrated Foods Plc shut down its cocoa processing plant in 2015 due to debt issues (ICIR Investigation). Evans Medicals, once a prominent pharmaceutical

company, lost its assets due to bad debt and was taken over by First Bank and Skye Bank in 2017 (ICIR Investigation).The Nigerian manufacturing industry faces challenges related to foreign exchange scarcity, high production costs, poor operating environments, policy inconsistencies, and debt problems, which have resulted in the closure of numerous companies (ICIR Investigation).This situation has prompted concerns about the decline of industries and calls for government intervention (ICIR Investigation).

In the face of the challenges plaguing businesses in Nigeria, it becomes evident that embracing effective management tools and strategies is essential for establishing and maintaining successful company operations. Implementing methodologies such as lean manufacturing, machine failure analysis, and other modern management approaches can offer a promising path towards resilience, efficiency, and sustainable growth for companies operating in this demanding environment.

### **2.3 Evolution of Lean Manufacturing in Industrial Systems**

Lean manufacturing, often referred to as Lean, is a comprehensive production practice and management philosophy aimed at enhancing efficiency, minimizing waste, and continuously improving operational processes in industrial systems. The evolution of Lean manufacturing can be traced back to its roots in Japanese manufacturing practices, most notably the Toyota Production System (TPS). This section explores the evolution of Lean manufacturing from its early stages to its global adoption, highlighting key milestones and its impact on industrial systems presented in Figure 2.1.



**Fig 2.1:** The Evolution of Lean Manufacturing in Manufacturing Industry

**2.3.1 Origins in Japanese Manufacturing:** Lean manufacturing originated in Japan, primarily through the pioneering work of Toyota. The Toyota Production System (TPS), developed by Taiichi Ohno and Shigeo Shingo in the 1950s, laid the foundation for Lean principles. Key elements of TPS included just-in-time (JIT) production, autonomous workgroups, and a relentless focus on eliminating waste (Womack J.P., Jones D. T., and Ross, D., 1990).

**2.3.2 Globalization of Lean Principles:** In the 1980s, Lean principles began to gain recognition worldwide, especially in the United States. James Womack, Daniel Jones, and Daniel Roos, in their influential book "The Machine That Changed the World" (1990), introduced the term "Lean" to describe the TPS and its principles. This publication marked a significant step in the globalization of Lean manufacturing concepts.

**2.3.3 Lean Six Sigma Integration:** In the late 20th century, Lean principles were integrated with Six Sigma, a data-driven methodology for process improvement. The resulting framework, Lean Six Sigma, combined Lean's focus on waste reduction with Six Sigma's emphasis on quality and defect reduction. This integration increased the effectiveness of Lean practices in various industrial systems (George, 2003).

**2.3.4 Beyond Automotive Industry:** While Lean principles initially found their place in the automotive industry, their applicability expanded to various other sectors, including aerospace, healthcare, and service industries. The idea of improving efficiency, reducing waste, and empowering employees became relevant in different contexts (Liker and Choi, 2004).

**2.3.5 Digital Transformation and Industry 4.0:** With the rise of digital technologies, Lean manufacturing adapted to incorporate Industry 4.0 concepts. The integration of automation, data analytics, and the Internet of Things (IoT) enabled real-time monitoring, visualization, and control of production processes. Lean principles are applied alongside digital tools to optimize operations (Kagermann, 2013).

**2.3.6 Sustainability and Green Lean:** In response to environmental concerns, Lean principles evolved to address sustainability. Green Lean, or environmentally conscious Lean, focuses on reducing waste in the form of energy, materials, and emissions. Organizations increasingly adopt Lean practices as part of their sustainability strategies (Bhasin, 2018).

**2.3.7 Lean as a Management Philosophy:** Lean manufacturing has become more than a set of tools; it is now regarded as a holistic management philosophy. Organizations embrace Lean culture, emphasizing employee involvement, continuous improvement, and a customer-centric approach. The Lean philosophy extends to leadership, strategy, and organizational culture (Liker, 2004).

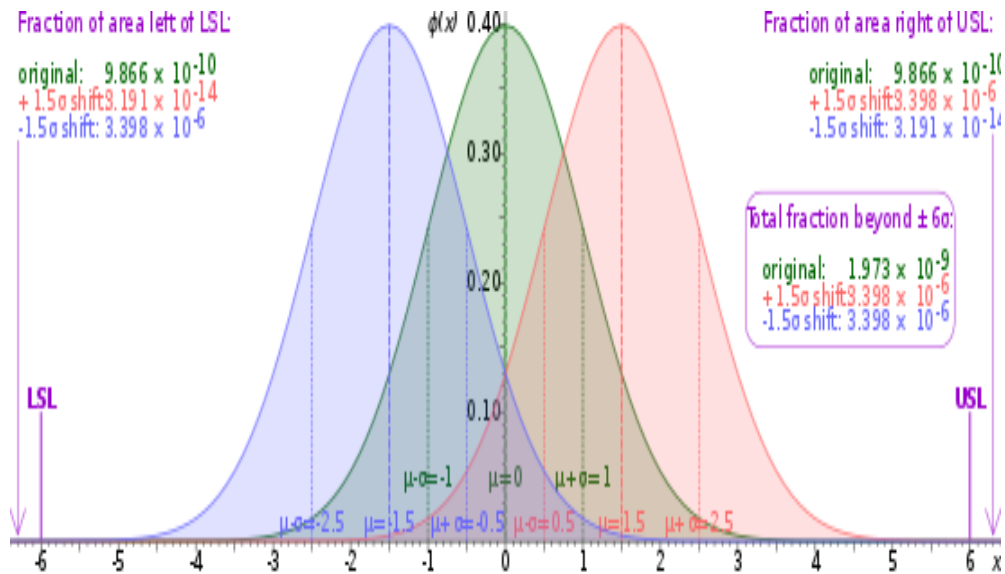
**2.3.8 Lean in the Age of Disruption:** In recent years, Lean principles have been adapted to address contemporary challenges such as globalization, supply chain disruptions, and the rapid pace of technological change. Lean practices remain essential for ensuring agility, resilience, and competitiveness in industrial systems (Shook and Jones, 2020).

The evolution of Lean manufacturing has been marked by its expansion from a production system to a comprehensive management philosophy. It continues to adapt and provide solutions to emerging challenges in industrial systems, making it a fundamental framework for achieving operational excellence.

## **2.4 Overview on Lean Manufacturing**

Lean is a concept that refers to statistical modelling of manufacturing processes and it's defined as one that produces no more than 3.4 failures per million chances. The first specification, "ISO 13053:2011," was released by the ISO-International Organization for Standardization (2011).

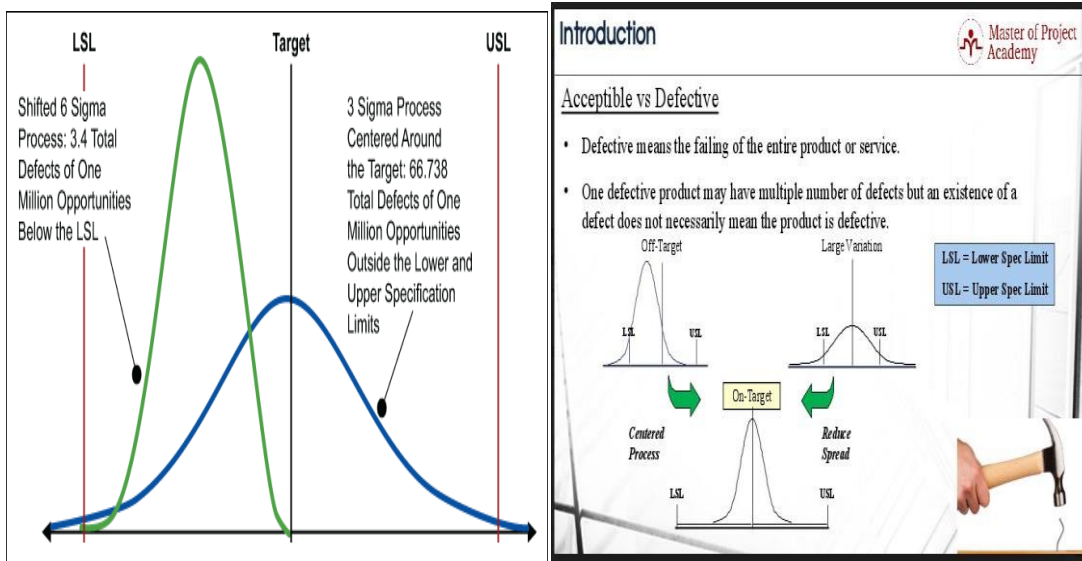
Sigma denoted as  $\sigma$  in Greek symbol which is translated with letter "S", and it is applied in statistics standard deviation. An average or mean value ( $\sigma$ ) denotes the 'center' of any family of data emerging from a numerical focused process calculation activity, and a sigma (standard deviation)  $\sigma$  denotes the degree of intrinsic variability. Standard deviation is calculated as the total variances within a set of data and their mean.



**Fig 2.2: Lean's Statistical Hypotheses are Focused on the Gaussian Distribution.**

**Source:** Yang *et al.*, (2020).

The axis on the horizontal bar shows length from the average, expressed in elements of sigma or  $\sigma$  (standard deviation) with the mean  $\mu$  (mu) at 0. The higher the  $\sigma$  value, the higher the stretch of values based on curve on green color,  $\sigma = 1$  and  $\mu = 0$ . The lower and upper specification limits (LSL and USL) are separated from the mean by 6 points. Because of Gaussian distribution numbers that are far from the average are highly improbable—roughly too high and the same too low in one in a billion. There is still a safety cushion if the mean moves 1.5 standard deviations right or left (also referred to like 1.5 shift of sigma, indicated blue (1) and red (3)). Sigma ranking representing the percentage or yield of zero-defect goods manufactured by a production process can be applied to describe their maturity specifically, value standard deviations of a Gaussian distribution the ratio of zero-defects results corresponds.



**Fig 2.3: Statistical Explanation of Lean.**

**Source:** Kaufmann *et al.*, (2019).

## 2.5 Critical Success Factors (CSFs) on Successful Applications of Lean Manufacturing

CSFs are variables that are crucial to an organization's achievement, on the reason that when the elements' goals aren't accomplished, then the organization will fail badly. They denote the components that are required for a project to succeed. CSFs are crucial ingredients in the application of Lean projects; without them, a project has a slim chance of succeeding. CSFs for implementing Six-Sigma identify the critical components in the scenario the project has a slim possibility of success from the standpoint of Lean project implementation. It is critical to understand SS's Critical Success Factors to successfully implement Lean projects. CSFs methods are more used and adopted in variety of various disciplines to find out important characteristics that are important to the accomplishment of any program or process in a study to discover the CSFs for SS in the Turkish carpet industry.

Furthermore, four CSFs for lean in SMEs which include (Kaufmann *et al.*, 2019): Management and leadership, Capital, Competency and skills, Continuous improvement practice. Recognition on CSFs is vital for Lean implementation efficacy. Many studies have argued that

management responsibility, infrastructures, technique and tool know how, project priority and selection, project skill, supplier and human resource management, customers satisfaction, effective business strategy, education and training and DMAIC-Define Measure Analyze Improve Control methodologies are all CSFs for Lean implementation. Laosirihongthong *et al.*, (2017), while applying the AHP-Analytic Hierarchy Process postulated six factors which are critically invaluable for Lean implementations in organizations. In doing this, a huge body of literature was searched so as to find out the factors which contribute to effective Lean deployment.

As a result of their research, six criteria were identified and explained below as rationale for each of the Six Critical Success Factor elements:

**2.5.1 Leadership, Engagement, and Dedication from Top Management:** Successful Lean adoption necessitates effective organizational culture change, which also nearly not possible to thwart an organization with no determined struggle by management targeted at driving frequent enhancement, employee involvement, and supply chain cooperation. Lean implementation relies heavily on the Upper-level management leadership, involvement, and dedication because it increases performance by influencing other elements such as total quality management (TQM) techniques. The top management of the organization should really be involved in the Lean initiative by not only physically attending each Lean training, meeting with employees and answering their questions, dropping by each lean training, but also coming on lean shows unannounced, conducting site supervision thereby observing first-hand how deeply Lean is established in the culture; and monitoring the projects at short intervals and receiving weekly summary reports from the tracking system which provides an overview of the Lean project's progress including monthly assessments incorporating database and master black-belt group.

**2.5.2 Training on Lean Methodology, Tools, and Methodologies with Focus on Understanding:** When implementing large changes in a business, workers education or

training has been acknowledged as a vital tool of production management. Under quality similarity concepts with training should focus both approaches and tools in issue solving, statistical process control and good communication when it is required, for instance, empowering people into problem solver and creative. Yang *et al.*, (2020), opted that, if the improvement effort is to be continued, staff must be trained in tools and procedures on a regular basis, since training program is ongoing should enable them find new concepts to enhance the organization and take on more responsibility for making changes.

**2.5.3 Lean and Business Techniques Relationship:** Lean cannot be viewed as a separate operation; it necessitates dedication to the entire idea than just the application of a small quality-improvement practices and tools. Top management must understand how the Lean strategy and other business strategies are intertwined to improve the organization's overall competitiveness. Because most businesses compete on profit, Lean systems should be accepted to foresee business processes profit oriented while addressing alterable, which heads to maximum scrap rates, minimum productivity and maximum rework rates.

**iv. Lean and Customers Relationship:** Most significant elements for effective Lean application are the capacity to attach the customer's satisfactory strategy. The client can be involved through the starting to the finish of the Lean strategy. The identification of client wants, requirements, and expectations should be the first step in any project. As a result, the method of connecting this concept to the client can be broken down into double parts: Defining and identifying the inner process, as well as the major outputs and inputs of these methods also determining the input or profit may be decreased or enhanced; Defining and identifying the customer expectations, requirements and needs

**2.5.4 Prioritization of Projects and Project Management:** For a successful lean selection of projects for process/product review and enhancement, deployment, prioritization and are

crucial. The ineffective definition and selection of projects results in delays and a lot of frustration. In addition, 23 prior research show that project team leaders and members should acquire excellent project management tools and procedures as part of the black belt training program. Because Lean is a project-based method, members of the team must possess project management abilities to fulfil some milestones or deadlines while the project is in progress.

**2.5.5 Connecting Lean and Suppliers:** Applying this method necessitates linking the constant enhancement strategy to suppliers. Relationship between the few suppliers in business enterprise for Long-term cooperatively as possible can aid the delivery of maximum quality services and/or materials. By promoting increased suppliers focus to both quality enhancement and customer expectations, keeping little amount of supplier increases productivity and quality of the product for buyers. Henderson and Evans (2019), added that connecting the Lean strategy to a small number of suppliers makes it flexible to solve delivery and quality problems. Effective linking promotes suppliers to participate in the product design process of the buying firm, giving them the opportunity to provide proposals for enhancement, component flexibility and quality products. The concept can also assist buyers in locating the most cost-effective materials and supplies.

**Table 2.2:** Summarizes the Six Parameters for Effective Lean Deployment in an Organization

	<b>CRITICAL SUCCESS FACTORS (CSFs)</b>	<b>DESCRIPTION</b>
1.	Leadership, engagement, and dedication from management.	Top leadership making enough financial support available; Participating in progress review in the project meetings; Effectively relationship towards client wants, requests and expectations across the enterprise.
2.	Training on Lean methodology, tools, and methodologies with focus on understanding.	Creating official training programs; Allocating training budgets; and Assessing comprehension of all training courses
3.	The application of Lean in corporate strategy	Developing and communicating functional/business concepts to all limits of the industries.
4.	Linking Lean to customers	Client objectives, requirements, and expectations are identified, and the common goals are communicated to all levels of the organization and the customer.
5.	Prioritization of projects and project management	Identifying the project's timeframe and assigning power and responsibility to each project management stage.
6.	Connecting Lean to suppliers	Identifying all capable vendors who are committed to constant improvement. Suppliers are informed about business and functional strategies.

In addition to the above, Khan, O. H. (2022) added four other critical success factors for successful implementation of Lean, making them 10. The elements include:

**2.5.6 Project Management Skills:** Black Belts lead project teams to implement and prove enhancements in processes, goods and services. Lean is a system-focus enhancement techniques thereby Black Belts lead project teams to find and execute enhancements in goods, processes and services. Lean group, which includes of master green, black and masters' black belts, is taught the project management procedures and tools. Black belt works on projects in a year (4-6) on average, but a green belt only works on 1-2 projects per year on average. Majority of Lean projects collapse due to a lack of project management know how, a failure to create and enforce ground rules, and a failure to specify the roles and responsibilities of the meeting

participants. Above 9,000 world Lean project were active or closed at 3M, along above 8,000 projects completed couple above 160 customer projects completed or active.

**2.5.7 Recognition and Rewards:** These are one of the facilitators that maximizes employees' potential and involvement in the quality improvement process, making them most important offers to the industrial quest for quality. Employee advancement considerations were linked to Green Belt training, which was one of Jack Welsh's noteworthy strategic innovations. As a result, each worker that wishes to be accepted for promotion at GE Appliances should be Lean green belt equipped. Without thorough Lean training and a completed project, no one at GE will be promoted (including senior executives).

**2.5.8 Communication:** Excellent communication is a very effective strategy to overcome hostility or reluctance to management initiatives and it helps retain excitement for quality improvement programs inside the company or organization. Effective communication is essential for aligning employees with company objectives. Employees, front-line employees, and middle management focus on goals that have little or no link to the corporate goal because of insufficient and inconsistent communication. Because the glue that holds the bricks of the quality management process together is communication, it's vital to convey both how and why of Lean as soon as can and create opportunities for workers to develop their satisfaction limit from training mediums. An implementation plan for communication emphasizing on advantages of Lean process and quality of how the process works is considered as crucial in overcoming two primary worries related with Lean's cultural transformation which are (a) afraid of disappointing to achieve current standards (b) afraid of change.

**2.5.9 Empowerment and Employee Participation:** People must be free to participate in continuous improvement activities in a quality environment which reduces decision-making to the simplest level possible. Lean project teams, black/green belt training for every cadre, and

appropriate rewards, recognition including awards systems encourage employee participation and empowerment. Since the concept of change implementation in an organization is also to optimize the participation of all staff, it is essential that each of the employee must understand his or her role in achieving the desired excellence. It entails employees sharing a shared knowledge of need and quality of their participation to keep the quality standards going. The premise that the significant method innovation strategies came through the people who are performing the job underpins the crucial necessity of employees' involvement and empowerment in an organization's quality process. It is essential to note here that since there are Critical Success factors, there exists also CFFs-Critical Failure Factors of implementing Lean Six and Lean as highlighted by Albliwi *et al.*, (2018), but the explanation of those CFFs is beyond the scope of this work.

## **2.6 How to Identify and Select a Lean Project**

The proper recognition and choosing of projects is required based on applications of the Lean strategy, and the selection of the suitable project for Lean is one of the essential success elements for Lean activities. Flifel *et al.*, (2021) provides resources for identifying potential projects, highest and lowest part approaches, the project selection criteria, project appraisal guidelines, picking requirement that will be exactly selected according to the organizational mission, functionality and needs, as well as sophisticated technologies and methods for project selection highly suggested in the literary guidelines of choosing the project. Pande (2019), proposed that possible lean projects can be identified through a variety of sources, which Flifel *et al.*, (2021), modified to be sources of potential project ideas, and consider them to be external, internal/external, and internal. External sources are concerned with issues and opportunities to meet customer requests, respond to market trends, and counteract rivals' actions. This type of source includes the viewpoint of the consumer, the perspective of the market, the opinion of the supplier couple with the comparison with competitors.

External/Internal sources are used to identify obstacles that a company faces in defining and achieving its strategic objectives. Internal sources, refer to the voice of employees and voice of process, are concerned with challenges and opportunities identified within a company and its procedures. However, proactive resources, retroactive, internal and external were highlighted by Marques *et al.*, (2018), as four phases namely: External, Internal, Retroactive, and Proactive Resources.

- i. Information gotten within a corporation that is readily available or deliberately gathered is referred to as internal sources.
- ii. Data from outside the firm that is either available or deliberately gathered is referred to as external sources.
- iii. Existing or previous data from within or outside a firm are considered retroactive source.
- iv. Proactive sources can be discovered both inside and outside of a corporation, and they are usually not immediately available, necessitating the use of proactive tactics to get it.
- v. IRS-Internal retroactive sources: These include performance information which also includes findings inspection, test, internal commercial and technical reports, capital, internal processes, finances etc.
- vi. ERS-External retroactive sources: Data from customer surveys, ratings of suppliers and subcontractors, including complaints from customers, demands, and other external retroactive sources may be incorporated.
- vii. Internal proactive sources: These include data from ideation meetings, staff suggestions, and the report of personal assessment relative to core elements within a particular model of perfection, among other things.

viii. ERS-External proactive sources include development or research operations in combination with scientific research centers, 3<sup>rd</sup> party survey, however, reports of personal assessment or external elements based on a specific model of perfection, and so forth.

In general, there are two approaches to developing Project Management methodologies (Kaufmann *et al.*, 2019): highest and lowest part. The top-down method is frequently associated with large "black belt" projects and is intimately tied to corporate strategy and consumer expectations. Senior executives use this strategy to analyze major issues and performance targets, and then propose strategic improvement projects that serve as a foundation for Lean winners and groups to identify essential features and processes, as well as chances for improvement.

#### **2.6.1 Selection Process for Lean Project by Pande *et al.*, (2019) includes:**

- i. Creating a list of probable project candidates - information about listed projects should be provided and completed in a professional and unambiguous manner.
- ii. Instituting a criterion for project selection – A criterion for selection of project can be developed in line with the mission and predetermined specifications.
- iii. Project prioritization – the selected projects are arranged and evaluated within the developed criteria to get a rated outcome.
- iv. Project selection – The most highly ranked initiatives are tested and chosen thereby a case is created to gain upper management authorization.

### **2.6.2 Organizational Guidelines for Choosing Lean Projects:**

Various writers have provided guidelines for selecting Lean projects, among which the following can be chosen reported by James Womack and Daniel Jones (2017):

- a. In terms of financial and process efficiency enhancement effect, the identified problem should be of the utmost importance for a corporation.
- b. Project objectives should be clear, explicit, attainable, practical, and measurable, with a high chance of success.
- c. design selection criteria can be focus on realistic and accurate measurements.
- d. Project importance should be communicated throughout the organization, and all stakeholders can be dedicated to the design's outcome couple with a solid understanding of tools and methodology of Six-Sigma.
- e. The project's scope should not be too large, and it is strongly advised that it be completed in four to six months.

A sense of demand can be developed in accordance with the importance of Lean initiatives designs can possess high management aid, with barrier removal, resource provision, and long-term sustainability. The definition of project selection criteria necessitates a thorough investigation.

The criteria, from Pande *et al.*, (2019), is divided into three concepts:

- i. Feasibility criteria.
- ii. Business benefits or outcomes
- iii. The influence on the organization

Business results or benefits include influence from outside customers and client expectations, competitive location, effect on corporate strategy and impact on essential skills, capital effects, dependability or sequence, trend and urgency.

## **2.7 Lean Professionalization and Certification**

Standard managements were mostly limited to the manufacturing of floor incorporated with statisticians in a distinct standard department prior to the introduction of Lean. Lean forms quality management by using elite ranking nomenclature like that used in judo (martial arts) to form a hierarchy which transverses corporate functions and levels. The Management and Strategy Institute designed the Lean Professional (SSLP) particularly for them. It is intended to provide students on a thorough training of both Lean and Lean principles, as well as how to work effectively with Lean principles in a manufacturing context. Lean is a manufacturing or production improvement methodology that is widely used. As a business word, it refers to a broad customer focus that focuses on offering more to the client.

The Lean certification validates experts who can detect and eliminating risks, errors, or faults in a business process. As part of their Lean implementation, GE and Motorola developed certification program. As a result of this strategy, some organizations started offering Lean certificates to their workers in the mid-1990s; and by 2008, the Motorola University collaborated with the LSS-Lean Lean Professionals in the society to generate equivalent certification requirements recognized for Lean Certification.

Certification requirements for black and green belts varies by company; while other industries merely need completion of a Lean project courses, there is no standardized certification organization, and many quality associations offer various certifications for a price. For example, those seeking Black Belt certification must pass through good grade exam along with

submitted affidavit stating that they have finished one or two projects plus at least three-years of practice knowledge, according to the American Society for Quality.

## **2.8 Hierarchical Roles for Successful Lean Project Application**

Lean defines several roles that must be fulfilled by the various levels for a project to be successfully implemented.

**a. Executive Leadership:** Those that make up this level are the chief executive officer (CEO) and other groups of higher managers, which oversee establishing a Lean implementation vision. This level of the organization's hierarchy also provides other custodians with the resources and freedom they require to overcome change stability and departmental hurdles.

**b. Champions:** They oversee Lean implementation throughout the organization. They are recruited from high management by the Executive Leadership. Black Belts look up to champions as mentors.

**c. Master Black Belts:** Champion-identified Master Black Belts serve as Lean in-house coaches. They devote their working time to Lean, guiding green and black belts and supporting Champions. Furthermore, statistical tasks, also promise that Lean is used uniformly work responsibilities and within departments.

**d. Black Belts:** To apply Lean to specific projects, Black Belts works on the survey of Master Black Belts. In addition, they devote complete percent of their period to Lean. They are generally concerned with Lean project specific leadership and project execution with special tasks, whereas Master Black Belts and champions are mostly concerned with identifying Lean projects and functions.

**e. Green Belts:** The Green Belts are employees who, in addition to their regular tasks, apply Lean under the supervision of Black Belts.

To make sure that they move within the method and apply the input strategy effectively, all these professionals will require additional training. Some companies utilize different colors of

belt (yellow belts) for worker who have basic Lean tool training and conventionally engage in white belts and projects for those who are taught the principles locally but doesn't engage in the design team. As a special case alternative, "orange belts" are also mentioned.

## **2.9 Methodology of Lean**

The lean manufacturing technique has risen to prominence as the major important quality efforts in the globe today. The most recognized instances of Lean success are General Electric and Motorola, others include Sony, Allied Signal and Citiban

### **2.9.1 Define Measure Analyze Improve Control (DMAIC):**

DMAIC technique is a realistic and rigorous way for managing Lean improvement operation and it is applied for projects targeted at enhancing already developed business process. The use of style belts in martial art to determine a leaner and expertise which distinguishes Lean from earlier quality control systems. Yellow, green, black, and master black belts are available. To move up the rankings, you must show that you have more project experience and have saved more money. To drive fact-based decision-making, black belts often control customers expected project teams employing a system for problem solving approach, project management abilities, change and analytical tools.

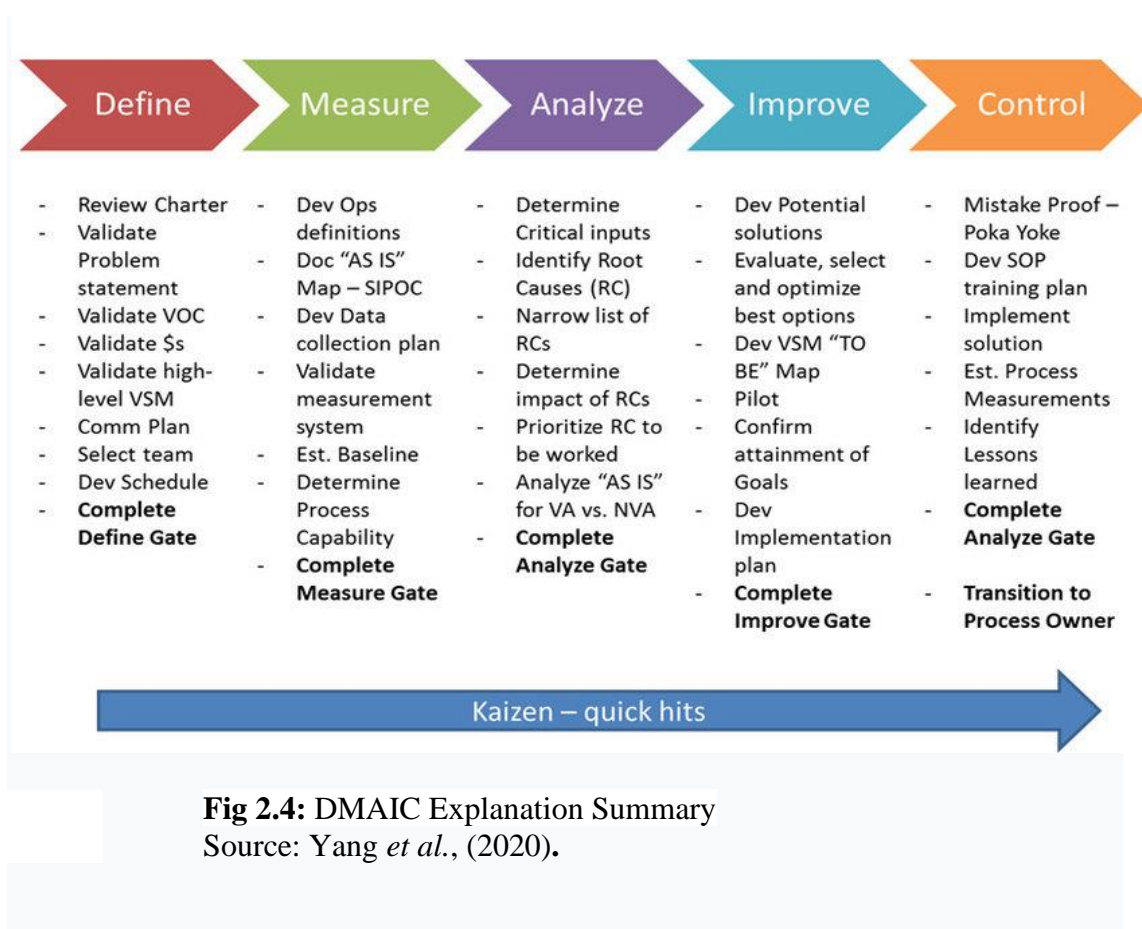
DMAIC is the acronym for the Lean problem-solving framework:

- ✓ **Define:** Define the areas that need to be improved.

Three primary activities are involved in the define phase.

- i. Create a group charter: The sequence concepts have been recognized including goal description and problem, business case, project scope, responsibilities and milestones, are all examples of business cases.
- ii. Customer Focus: Customer needs are converted into explicit requirements, and customer data collection methods are identified.

- iii. **Process Mapping:** Define the process first, and then tie the customer to it. Business process mapping is used to determine the benefits and applications of process mapping for an existing process.
- ✓ **Measure:** Measure the actual situation to the intended situation. The tasks completed during this phase are listed below.
  - i. Performance criteria are established, i.e., specification limitations that satisfy client requirements.
  - ii. Create a data gathering strategy and collect the information.
  - iii. The measurement system must be validated.
- ✓ **Analyze:** Investigate the core causes of the performance gap. The gathered data must be examined to focus on the origin of the problems. This phase's steps are as follows:
  - i. Evaluate the importance of each process step.
  - ii. Examine the information gathered and convert it into graphs and charts.
  - iii. Using cause & effect diagram, brainstorm the problem's causes.
  - iv. Further investigation into the problem's origins is done.
- ✓ **Improvement:** Ideas are discussed, chosen, and executed.
- ✓ **Controls:** For long-term viability are put in place.



**Fig 2.4:** DMAIC Explanation Summary  
Source: Yang *et al.*, (2020).

**2.9.2. Define Measure Analyze Design and Verify (DMADV):** This methodology has been utilized by organizations to projects target at producing process designs and new product in order to meet the needs of their consumers. When a consumer or client demands improvement in product, creation of complete current product or services, correction, DMADV is used. The use of these strategies aims to produce a high-quality product while keeping consumer requirements in mind, DMADV are the five project phases as shown in figure 2.5.



**Fig 2.5: DMADV Illustrated with Signs**

a. **Define:** Develops aims that are in within with client expectations and the industries overall techniques. Project managers spot the wants and needs those customers are most likely to value. Historical data, customer input, and other data sources are used to determine wants and needs. To guide the process, teams are formed. Customers' information is used to build metrics and other tests.

b. **Measure:** Critical to quality characteristics (CTQs), risks, manufacturing process capabilities and product capabilities are all identified and measured. The second step in the process is to gather data and record specifications using the stated metrics on a platform that can be used to guide the other processes. However, processes needed to make a successful product or service are subjected metrics to be evaluated later. Measurements are tested and then implemented by technology teams.

**Analyze:** To create and design alternatives, internal teams test the result of the manufacturing process that is the finished product or service to establish a data used by leaders to discover areas of process improvement that would improve the quality or manufacturing process a finished product or service. Teams put in place final processes and make improvements as needed.

**d. Design:** Create a better alternative related on the reports of the previous step's investigation.

Internal test results are compared to consumer requests and needs. Any modifications that are required are done. Before the finished product or service is generally launched, the improved production process is experimented, and research teams of customers give report.

**e. Verify:** Verify the design, do pilot runs, and finally turn the production process on to the process owner(s). The methodology's last stage is now underway. The methods may be tweaked once the product

or service is released, and user feedback is received. Metrics are created further to track ongoing client input on the product or service. New data may result in additional changes that must be handled; hence the initial procedure may lead to new DMADV applications in other areas.

DMAIC and DMADV have a lot in common because they're both used to:

- i. Minimise the number of flaws per million opportunities to fewer than 3.4.
- ii. Using data and statistical methods, find high-quality solutions to challenges.
- iii. Assist in achieving a company's financial and business goals.

## **2.10 Tools and Methods Employed by Lean Approach:**

Lean employs variety of effective developed quality management methods inside the distinct phases of a DMAIC or DMADV project.

Here is an overview of the main approaches employed in Lean.

- a. General linear model/ANOVA Gauge: ANOVA measures reproducibility and repeatability is a gauge systems analytical procedure that examines measurement system by applying ANOVA analysis of variance random effects concept.

- b. Regression-analysis: Entails statistical techniques for calculating relationships within a one or more independent-variable and dependent-variable, which can also be applied to measure the capacity of a relationship within variables and to forecast how they will be related comes time.
- c. Correlation, Correlation Analysis of Variance: ANOVA-analysis of variance is a technique from statistical approach that separates a variable set's observed aggregated variability in double parts, random factors and systematic parts. Random factors do not statistical effects on the given set of data, but systematic influences effects. However, on regression research, analysts use ANOVA experiments to determine the effect of independent data on the dependent variables.
  - i. 5-Why: The most essential origin cause analysis techniques in the Lean management equipment is the 5-Whys strategy. On their daily job, all group encounter hurdles. Utilizing the 5-Whys assists in identifying the inner cause of any defects and maintain the process from occurring failures and errors.
  - ii. Axiomatic design: A high-value modelling approach that lowers the number of alternative beginning ideas to one while using virtually no resources. It gives a motivation-satisfying conceptual design, and the selected setup is as near to the ideal as the system allows.
  - iii. Business Process Mapping/Check sheet: A visual picture of how company works, such as standards, responsibility and roles is known as BPM-business process mapping. BPM characteristics goes a further by giving a clear view of how to understand, analyze, and enhance an existing system. For a variety of causes, businesses schedule their method of operations.
  - iv. Cause and Effect Diagram, Scatter diagram, Chi-squared test: This is an example of quality concept that can be applied to highlight the link within paired data and

gives sufficient information on a manufacturing process is the Scatter Diagram. What exactly does *paired data* imply? The word *cause & effect* refers to a relationship within two types of data, but it can also apply to a relationship within a cause and another, or within numerous causes. Observe the association between product hardness and an ingredient, the relationship between a blade's cutting speed and differences in part vertical or relationship within lighting levels on the manufacturing ground and faults made in quality supervision of the product manufactured.

- v. Run charts/control chart/control plan.
- vi. CTQ-Critical to Quality tree: This is a diagram-based tool that helps in the development and delivery of high-quality goods and services. They are used to convert broad client needs into, executable, and quantifiable performance goals and can observe down through a broad aim to, quantifiable needs that can use to enhance performance utilizing a CTQ Tree.
- vii. Cost-Benefit Analysis (CBA): It is a concept that examine and analyze the estimated and projected opportunities and costs related to the project option to check whether it is financially viable. The societal value of a project is measured using CBA, which quantifies the project's society consequences and compares costs and benefits in financial terms.
- viii. Experiment design/Stratification: This is a simple, straightforward and strong, component for process improvement. Statistical experiments that can be used to run charts are normally overlooked, indicating in the run chart being neglected. This article entails the merits of a run chart couple with how to analyze and design one appropriately.

- ix. Pareto chart/ Pareto Analysis: Pareto Graph is a statistical chart that outlines the causes and effects of a problem in descending order of frequency and cumulative impact. To observe the causes, a histogram-graphic is used inside Pareto-chart. The Pareto Diagram is another name for this graph.
- x. Rolling throughput yield/Pick chart/Process capabilities:
- xi. Deployment of Quality Functions (QFD): A process for identifying consumers' wants to build a product or services that meets their demands the first time.
- xii. Enterprise Feedback Management (EFM) technologies for quantitative marketing research. Companies may now collect and analyze feedback from all stakeholders (customers, workers, partners, and so on) in a continuous, timely, and effective manner using Enterprise Feedback Management software.
- xiii. RCA-Root Cause Analysis is the approach of finding the underlying causes to develop acceptable ways. However, putting off fires and treating ad hoc defects, according to root cause analysis, is exceptionally successful than resolving and frequently preventing internal problems. In RCA, a collection of techniques, procedures and theories can be utilized to measure the origin causes of trend or an occurrence. Beyond flexible cause and effect, root-cause-analysis can show where system or processes caused or failed an issue in the initial place.
- xiv. Quality Loss Function (Taguchi method): From the moment the product is designed until the time it is sold to the consumer, Taguchi defined quality loss function as the loss inflicted on society by the product. It is a graphical representation of a range of defect parts which can all show in losses, can be measured in the local currency.
- xv. VSM (Value Stream Mapping): This is a tool for examining the material flow and information flow required to provide a product to a client.
- xvi. Suppliers, Inputs, Process, Outputs, Customers (SIPOC Analysis).

## **2.11 Researched Work on Application of some Management Techniques**

Around the world different ideas on achieving high productivity by implementing various models has been carried out in attempt to obtain a panacea to wastages, but it seems just one method cannot cater for the multi-facet issues faced by these organizations. This propelled research in lean and six sigma.

Maleka (2017) indicated that presently there is a high degree of integration between these two (lean and six sigma). Consultants and practitioners are influencing this integration while the academicians are researching the common holistic model. Mayeleff (2018) opined that some schools of thought have optimistically claimed that this integrated form Lean six sigma (LSS), represents the progression of Lean approach, and the LSS is becoming the new kaizen approach in the industry.

Improved performance means different things for different organization and based on report by Scott (2019), there has been a paradigm shift in the conception of improved organizational performance from profit, growth, productivity and stability under a rational system to quality, durability, and consumer satisfaction.

Lean approach and tools are a way to reduce customer's critical to quality (CTQ) issues and significantly improve cost and quality (George, 2019). Organizations measure the workability of implementing these models by high quality levels, increased returns on investment and profit margins, reduced cost amongst others; these concrete results successes are sufficient to bring back discipline and boost, when the organization tends to slip back into previous wasteful habits.

Bryne (2021) reviewed the benefits of implementing an integrated model on lean manufacturing, and concluded that LSS, if not just concentrated on efficiency but on growth

can function as a basis for advancement throughout an organization, i.e., it can enhance innovations in products, services, market and even the organizations underlying business model. Successes are visible where this integrated form LSS was implemented by Caterpillar with a clear-cut roadmap for change like the successful low-emission diesel engine. Streamlining its supply chain an impressive growth in revenues by about 80 percent was experienced (Maleka, 2014).

It was also reported by Teresko (2017) that Stiles and Associate enjoyed increase in customer service level, 95 – 99%; lead time, one-quarter to one-half the industry average; earning growth, two to four times the industry average; sales growth, three to five times the industry average; customer retention, 90% and above and productivity of 15% and rising per year. Based on the work of Laureani and Antony (2018) the benefits of LSS in manufacturing are, ensuring service/product meet customer need; removing waste; reduce incidence of defective products; reduce lead time; deliver correct product/service at the right time and place.

According to Thomas *et al.*, (2019), the subtle advantage of LSS is the progress of tradition towards kaizen and the LSS approach enables an organization to develop sophisticated statistical techniques and generally become more technical in their approach to problem solving.

Bergmiller and McWright, (2019), utilized diverse checks and balances to not only monitor production, facilities and processes but the processes of every actor (employee, employer, supplier, customer, etc.) involved in manufacturing processes, they applied the strategy of categorizing the foreseeable waste processes to be eliminated into eight groups termed the eight Muda (waste) for effective waste elimination to achieve elusive perfect production process.

## **2.12 Summary of the Literature Review and Research Gap**

Despite the extensive body of literature on some notable management and manufacturing techniques and their applications in various industries, there is a notable research gap when it comes to their specific implementation within the aluminum roofing sheet production sector in Nigeria. The literature review indicates that the aluminum roofing sheet production industry plays a vital role in the construction sector and the Nigerian economy. However, various factors, such as poor management, machine failures, supply chain mechanism, varying thickness, governmental policies and other factors in the production process, have negatively impacted aluminum industries. These issues have contributed to a decline in productivity, operational inefficiency, and possible customer dissatisfaction.

This study focused on utilizing research materials to investigate the factors that is affecting the decline in productivity of JAMBAZ Aluminum Roofing Sheet, located in Anambra Eastern part of Nigeria. Afterward, PRO regression model and maintenance strategic techniques developed from lean manufacturing tools were found suitable to eliminate the negative impact from the observed factors affecting the company, were applied to see the effect of these management tool in eliminating and increasing the productivity of a manufacturing company.

**CHAPTER THREE**  
**MATERIALS AND METHOD**

**3.1 Materials**

The materials used in this research is presented in Table 3.1.

**Table 3.1: Materials and their descriptions used in the study**

<b>S/N</b>	<b>Item</b>	<b>Description</b>
1	Questionnaire Forms	Physical paper-based forms and electronic forms used to collect responses from participants.
2	Pens and Pencils	Writing instruments used for completing paper-based questionnaires.
3	Electronic Devices	Phones and other devices used for conducting electronic surveys.
4	Interview Guide or Protocol	A physical document containing a structured list of questions or topics for guiding the interviews.
5	Recording Devices	Audio recorders and video cameras used to capture interviews for later analysis.
6	Note-taking Materials	Notebooks or electronic devices used by interviewers to take notes during the interviews.
7	Recruitment Documents	Documents used to recruit participants for the study.
8	Informed Consent Forms	Oral consent forms used to obtain participants' consent to partake in the study.
9	Data Analysis Software	Tools such as Excel for data visualization and Mini PYTHON for quantitative analysis.
10	Company journals, magazines, and bulletins	Internal publications and data storage systems used for reference and information gathering.

11	Internet Research	Online research conducted to gather information and data relevant to the study
12	Maintenance Log Sheets	Documents detailing maintenance records used for data collection and analysis.

*Source: Author*

### 3.1.1 Brief Background Description and Production System of JAMBAZ

JAMBAZ Aluminum Industry, located in Onitsha, Anambra State, Nigeria, is a prominent player in the aluminum manufacturing sector. Specializing in aluminum sheet production, the company has diversified its product range to include various aluminum products catering to diverse industrial needs. The company extended its production beyond roofing sheets to deliver a comprehensive range of aluminum products, including aluminum roofing sheets, extruded aluminum profiles, aluminum coils, aluminum foils, aluminum-based cladding solutions, and aluminum windows and doors. Table 3.2 presents the various classification of staff.

**Table 3.2: Workforce Classification**

Department	Number of Employees
Production	120
Quality Control	15
Research & Development	10
Administration	25
Sales & Marketing	30
Maintenance	20

*Source: Company's Human Resource Department.*

JAMBAZ Aluminum Industry operates through various segments, each integral to the overall functioning of the company. The production process of aluminum sheet comprises of different segments which includes raw material, material treatment, bonding and painting, quenching,

embossment and rolling, corrugating to finished product. Machines used in the manufacturing line of the aluminum sheet company is presented in Table 3.3.

**Table 3.3: Equipment Specifications and Applications in Aluminum Roofing Sheet Manufacturing.**

S/N	Equipment Name	Specifications	Application
1	DE coiler Machine	Capacity: 5-20 tons, Width: 500-1500 mm	Unwinds aluminum coils and feeds them into the production line.
2	Roll Forming Machine	Speed: 10-30 m/min, Width: 600-1250 mm, Power: 15-50 kW	Shapes aluminum sheets into desired roofing profiles.
3	Cut-to-Length Machine	Speed: 10-60 m/min, Width: 600-1600 mm, Thickness: 0.3-3 mm	Cuts roll-formed sheets to specific lengths.
4	Hydraulic Press Machine	Pressure: 50-500 tons, Stroke: 100-500 mm	Creates bends or curves in aluminum sheets for specific designs.
5	Embossing Machine	Speed: 5-30 m/min, Width: 500-1500 mm	Imprints patterns or textures onto aluminum sheets.
6	Corrugation Machine	Speed: 10-20 m/min, Wave Height: 15-75 mm	Forms sheets into corrugated shapes for added strength.
7	Shearing Machine	Capacity: 10-25 mm thickness, Width: 1000-3000 mm	Cuts aluminum sheets to required sizes and shapes.
8	Edge Trimming Machine	Speed: 10-50 m/min, Width: 600-1600 mm	Trims edges of sheets for a clean, precise finish.
9	Coating Machine	Speed: 5-30 m/min, Coating Thickness: 0.02-0.15 mm	Applies protective coatings or paint to sheets.
10	Annealing Furnace	Temperature: 400-650°C, Capacity: 5-50 tons	Heats sheets to improve ductility and reduce hardness.
11	Cooling System	Water/Air cooling, Capacity: Variable.	Rapidly cools sheets after heating to set final properties.
12	Slitting Machine	Speed: 10-150 m/min, Width: 600-1600 mm	Cuts wide coils into narrower strips.
13	Packaging Machine	Capacity: Variable, Automation: Semi/Full	Packages finished sheets for shipment.
14	Quality Control Equipment	Spectrophotometer (Model: ColorGuard-6000 Accuracy: $\pm 0.1\%$ ), Tensile Testing (3000 Capacity: 50 kN), and Surface Roughness Tester (Measurement Range: 0.01 to 50 $\mu\text{m}$ )	Measures thickness, hardness, color, and other parameters for quality assurance.

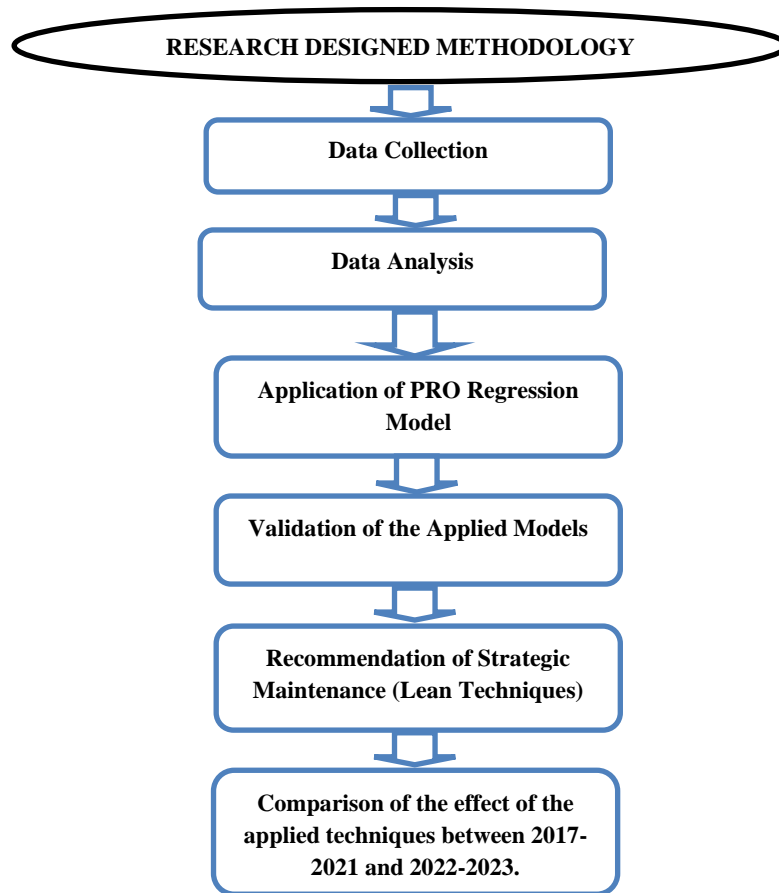
15	Material Handling Equipment	Includes forklifts, conveyors, and cranes.	Moves raw materials, semi-finished, and finished products within the facility.
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*Source: Machine and Maintenance Department.*

The machines presented in Table 3.3 are used in production line of the company, while the company produces three different types of roofing sheet classified by their size which includes 0.025 Inches (thin line), 0.063 inches (medium line), and 0.125 (thick line). This production specifications involves complex production and managerial processes which contributes to the human and machine partial productivity failures since the system is not purely automated, other factors may include external factors such as political factors, governmental policies, supply chain mechanism, environmental factor such as the IPOB every Monday sit at home declaration, COVID-19 pandemic etc.

### **3.2 Method**

This comprehensive background information provides an overview of JAMBAZ Aluminum Industry, including its workforce classification, operational segments, and the production process of aluminum sheets giving a meticulous process flow chart of the research methodology illustrated in Figure 3.1.



**Fig 3.1:** The Methodology Steps

### 3.2.1 Data Collection

Conduct on-site observations using questionnaire, company record book, and other data collection mediums was done from 2017-2021, to identify operational inefficiencies and bottlenecks in the aluminum sheet production, because every year, month, week or day has a significant factor/s that might affect an existing system. Structured questionnaires were distributed to current and former employees, customers, and analysts to gather insights into their experiences regarding the aluminum sheet company's productivity decline. These questionnaires focused on observations related to machine failures, maintenance costs, digital skills utilization, supply chain mechanism, external, managerial and other factors contributing to the declined productivity. In-depth interviews with key stakeholders, including management personnel, engineers, and maintenance staff, provided a qualitative understanding of the

challenges, particularly those related to machine maintenance and digital skills in manufacturing. Company magazines, bulletins, and data storage systems were analyzed to extract historical information and official communications about productivity issues, machine failures, and maintenance strategies. Electronic devices were used for conducting electronic surveys and interviews, while note-taking materials documented interview responses.

### **3.2.2 Data Analysis**

Quantitative data from financial reports were subjected to statistical analysis using Excel's plotting and graph tools to identify trends and patterns in machine failure and maintenance costs. Qualitative data from structured questionnaires and in-depth interviews were analyzed thematically to extract key themes related to digital skill utilization and workforce perceptions. The integration of both quantitative and qualitative analyses provided a comprehensive understanding of the factors contributing to the decline in productivity. Excel software facilitated the quantitative analysis of the gathered data, ensuring detailed visualization and effective interpretation of the results.

### **3.2.3 Application of production and revenue optimization model (PRO regression model).**

This research utilizes regression analysis approach to create a predictive maintenance model. The model focus on understanding the relationship between machine downtime and production rates, and how these factors affect overall productivity. The model was subject to the data collected from the company's maintenance records, production logs, and financial reports for the years 2017 to 2021.

The Key components of the model includes downtime analysis which evaluates machine downtime and its impact on production efficiency, next is cost management which analyzes maintenance and operational costs to identify potential savings, another component of the model is production efficiency optimizes production rates based on historical data and target

benchmarks, finally, revenue maximization which ensures revenue is maximized by aligning production output with market demands and minimizing unnecessary costs.

The following key variables were identified:

$t$  = Time in years (2017, 2018, 2019, 2020, 2021)

$D_i(t)$  = Downtime for machine  $i$  at time  $t$

$P(t)$  = Total production at time  $t$

$T(t)$  = Production target at time  $t$

$C_i(t)$  = Maintenance cost for machine  $i$  at time  $t$

$R(t)$  = Revenue at time  $t$

The objective of the model application is to Minimize downtime and maintenance costs to maximize production and revenue.

Total downtime for ***thinline***:

$$D_{thin}(t) = \sum_{i=1}^{10} D_{i,thin}(t) \quad 3.1$$

Total downtime for ***mediumline***:

$$D_{medium}(t) = \sum_{i=1}^{10} D_{i,medium}(t) \quad 3.2$$

Total downtime for ***thickline***:

$$D_{thick}(t) = \sum_{i=1}^{10} D_{i,thick}(t) \quad 3.3$$

Production Function:

$$P(t) = \alpha - \beta D(t) + \gamma(T(t) - D(t)) \quad 3.4$$

where:  $\alpha$ ,  $\beta$ , and  $\gamma$  are parameters to be estimated based on historical data, and  $D(t)$  is the total downtime across all machines and lines.

Revenue Function:

$$R(t) = P(t) * \text{Unit Price} - \sum_{i=1}^{10} C_i(t) \quad 3.5$$

Where unit price is the selling price per ton of production.

Cost Function:

$$C(t) = \sum_{i=1}^{10} C_i(t) + \text{Other Operational Costs} \quad 3.6$$

Optimization Problem:

This function tends to minimize the objective function (Total Cost) while maximizing productivity and revenue, this is achieved by application of Minimize (Z) linear regression function:

$$Z = \sum_{i=1}^n (R_i * P_i - C_i) \quad 3.7$$

Subjected to:

$$\sum_{i=1}^n a_{ij} P_i \leq b_j, \forall_j (P_i \geq 0, \forall_j) \quad 3.8$$

Where: Z is the total profit,  $R_i$  is the revenue per unit of product  $i$ ,  $P_i$  is the production quantity of product  $i$ ,  $C_i$  is the cost associated with product  $i$ ,  $a_{ij}$  is the coefficient representing resource  $j$  consumed by product  $i$ ,  $b_j$  is the availability of resource  $j$ .

To validate the PRO model, a regression analysis can be performed using historical data. The statistical model can be formulated as follows:

$$R(t) = \beta_0 + \beta_1 D(t) + \beta_2 P(t) + \beta_3 T(t) + \beta_4 C(t) + \epsilon(t) \quad 3.9$$

Where the dependent variable is  $R(t)$  revenue at time  $t$ , independent variables include  $D(t)$ ,  $P(t)$ ,  $T(t)$ , and  $C(t)$ ,  $\beta_0$  = Intercept term,  $\beta_1, \beta_2, \beta_3$ , and  $\beta_4$  = coefficients for the independent variables, and  $\epsilon$  error term.

The goodness of fit (GOF) of the model which indicates how well the independent variables explain the variability of the dependent variable, which for the company the dependable variable is the revenue. The GOF is determined using:

Where  $\hat{R}$  is the predicted revenue from the regression model and  $\bar{R}$  is the mean of observed revenues. P-values for coefficients was used to determine the statistical significance of each

coefficient. If the p-value is less than 0.05, the corresponding variable is considered significant in predicting the revenue. Next to validate the GOF is the application of residual analysis, where the residuals (the differences between observed and predicted values) is applied to check for any patterns that suggest a poor model fit.

$$\text{Residual} = R(t) + \hat{R}(t) \quad 3.10$$

By applying the optimization model, the company aims to reduce machine downtime, lower maintenance costs, improve production efficiency, and ultimately enhance revenue generation. The model provides a systematic approach to identifying and addressing key factors affecting productivity and financial performance.

### **3.2.4 Recommendation of Strategic Maintenance (Lean Techniques)**

In order to address the decline in productivity at JAMBAZ Aluminum Roofing Sheet Company, a comprehensive application of lean manufacturing techniques is essential. These methodologies are designed to identify and eliminate waste, streamline processes, and enhance overall efficiency. The following tools, including value stream mapping, eight deadly wastes approach, work leveling (Heijunka), takt time, and fishbone diagram (Ishikawa), will be implemented to optimize production processes and improve operational performance {Swarnakar, V., Bagherian, A. and Singh, A., (2023); Francescatto, M., Neuenfeldt Junior, A., Kubota, F., Guimaraes, G and de Oliveira B., 2023}.

#### **Eight Deadly Wastes Approach**

The eight deadly wastes Approach focuses on identifying and eliminating eight types of waste: defects, overproduction, waiting, non-utilized talent, transportation, inventory, motion, and extra processing (Mishra 2022). In this study, we will systematically examine each aspect of the production process to uncover these wastes. By implementing targeted measures to address and reduce these wastes, we aim to optimize resource utilization, enhance operational

efficiency, and improve overall productivity within the company (Rodriguez and Walter (2017); Oba *et al.*, (2024); Zonta T., da Costa C., da Rosa Righi, R., de Lima, M., da Trindade, E., and Li, G. (2020)}.

### **Work Leveling (Heijunka)**

Work Leveling or Heijunka, will be applied to balance production by distributing workloads evenly across all processes and employees. According to David *et al.*, (2024) this method aims to minimize fluctuations in production volume and avoid bottlenecks by leveling the type and quantity of production over a given period. By smoothing out production schedules and aligning them with customer demand, Heijunka helps to reduce inventory costs, improve delivery times, and increase the flexibility of the production system (Theissler *et al.*, 2021).

### **Takt Time**

Takt Time is the rate at which products must be produced to meet customer demand (Csiki *et al.*, 2023). In this research, we will calculate the Takt Time based on customer orders and available working hours. This metric will be used to align the production pace with market requirements, ensuring that production activities are synchronized with customer demand. By setting and adhering to the Takt Time, we can optimize workflow, reduce cycle times, and enhance the overall efficiency of the production process. According to Yusuf *et al.*, (2018); Gupta and Patel (2018) Takt time can be expressed mathematically as follows:

$$TK = \frac{A_t}{c} \quad (3.1)$$

Where:  $A_t$  is the available time per shift (in seconds),  $C$  is the customer requirement per shift (in units). The available time per shift ( $A_t$ ) is calculated by subtracting the time allocated for breaks ( $B$ ) from the total time per shift ( $T_s$ ):

$$A_t = T_s - B \quad (3.2)$$

Where:  $T_s$  is the total time per shift (in seconds),  $B$  is the time allocated for breaks (in seconds). The customer requirement per shift ( $C$ ) is derived from the total customer demand ( $D$ ), the number of working days ( $n$ ), and the number of shifts ( $s$ ):

$$C = \frac{D}{n*s} \quad (3.3)$$

Where:  $D$  is the total customer demand (in units) per day, week, or month,  $n$  is the number of working days per week, or month and  $s$  is the number of shifts per day. Putting all the variables together, the complete and improved equation to calculate the takt-time modified by the applied model by Ota *et al.*, (2023); Odeyinka *et al.*, (2023) is given as:

$$TK = \frac{T_s - B}{\frac{D}{n*s}} \quad (3.4)$$

Incorporating these lean manufacturing tools into the analysis and optimization of the Aluminum roofing sheet production process will provide a comprehensive framework for identifying inefficiencies, reducing waste, and enhancing productivity. These methodologies are integral to developing a robust and sustainable production system that can thrive in a distressed economy. The various applied models were analyzed using PYTHON and Excel software

### **3.2.5 Comparison of the effect of the applied techniques**

This phase tends to disclose the percentage of positive result after successful application of the optimization model and the maintenance and management techniques. The process involved calculating the average of the collected data for the annual production rate, machine downtime, maintenance and supply chain costs, and annual expenses and revenue between 2017 to 2021 and 2022 to 2023.

## CHAPTER FOUR

### RESULTS AND DISCUSSION

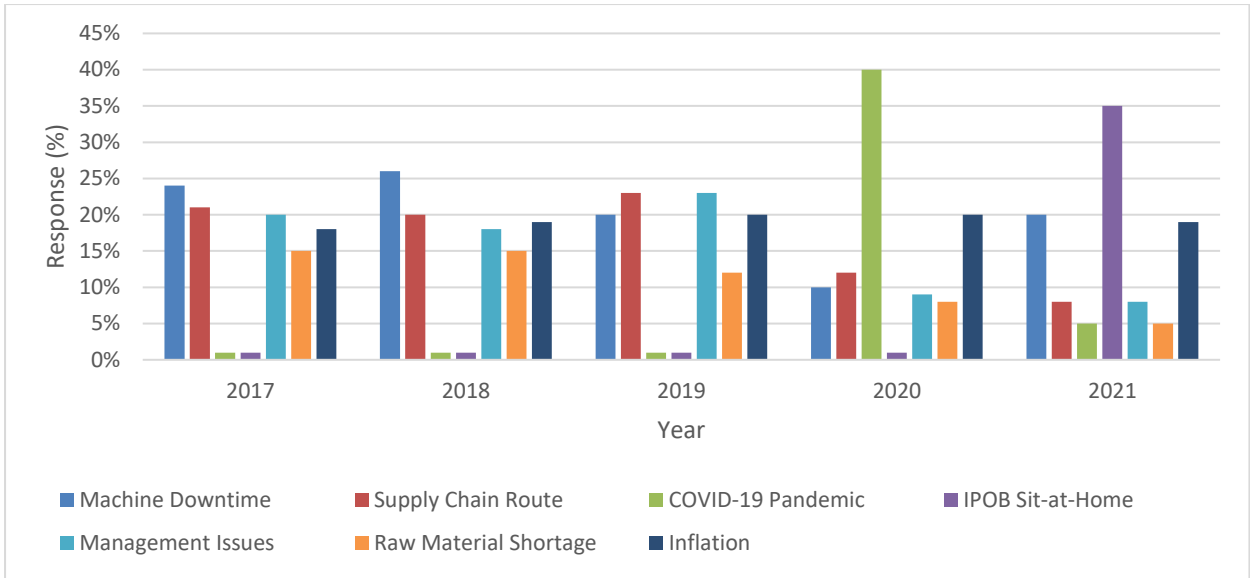
#### 4.1 Results

The results obtained in this research are presented in this chapter. Figure 4.1 – 4.9 illustrates the results from the data collected from the company, sampling the current situation of the company. Figure 4.10 – 4.13 presented the result achieved from the applied model. Figure 4.14 – 4.15 and Table 4.1 – 4.10 presents the different managerial and maintenance strategies developed from lean management techniques. Figure 4.16 – 4.18 presents the various comparison results from the previous situation of the company and the effect of the applied optimization model and maintenance strategic techniques.

##### 4.1.1 Presentation of Data Collection

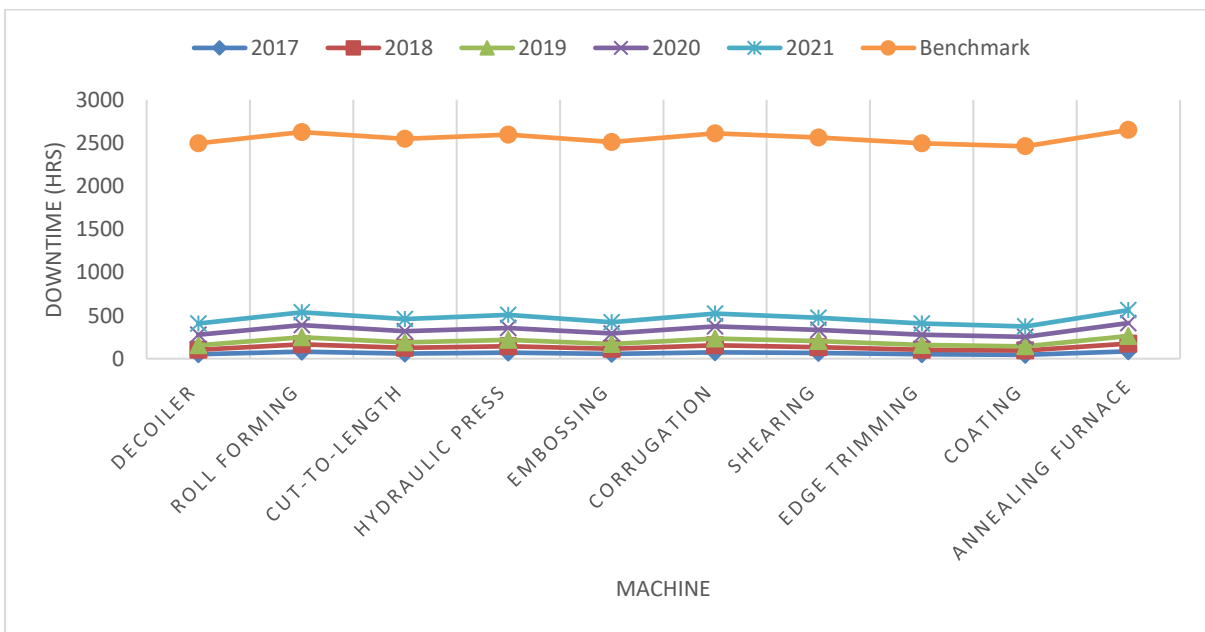


**Fig 4.1:** Company's Production Rates and Targets  
*Source: Inventory and Production Record Dept. (2017-2021)*



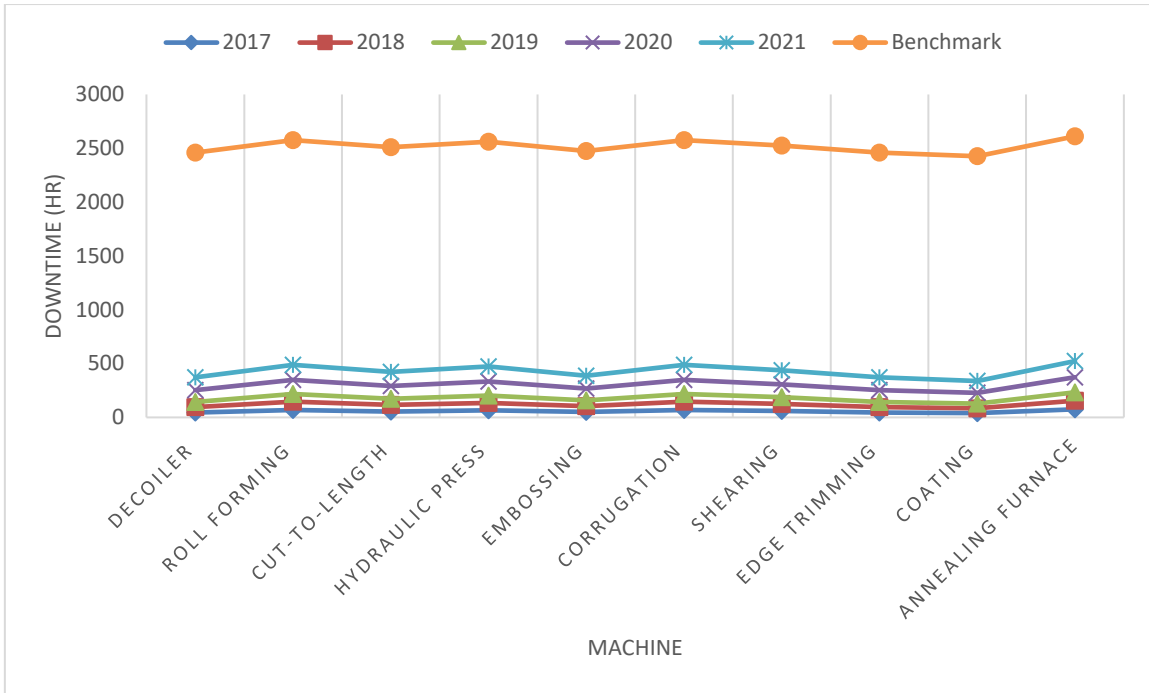
**Fig 4.2: Factors Affecting Productivity of JAMBAZ Aluminium Roofing Sheet Company (2017-2021).**

*Source: Questionnaires (2021)*

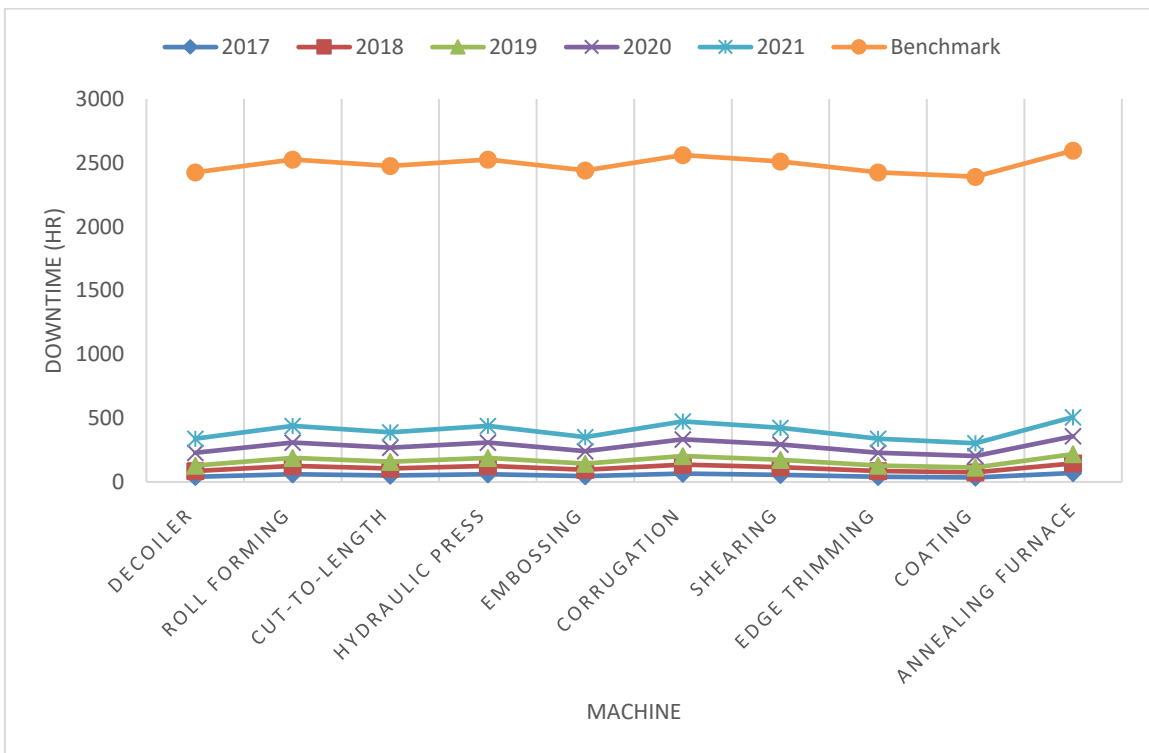


**Fig 4.3: Machine Downtime and Benchmark for Thin Line (0.025 Inches).**

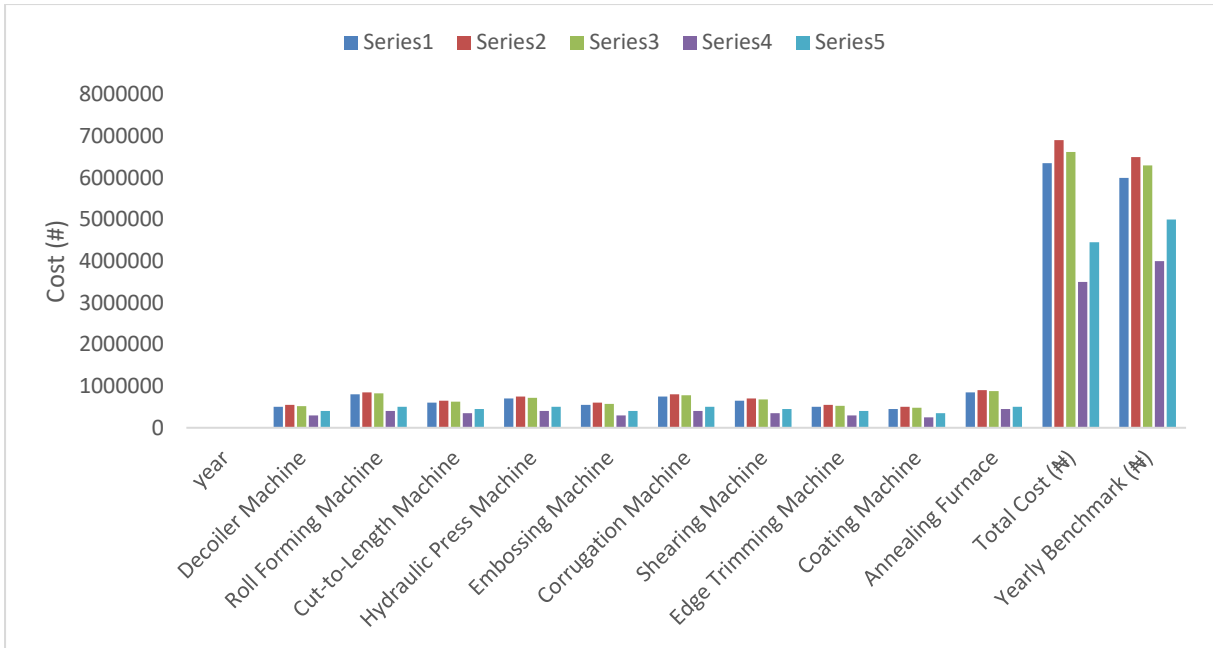
*Source: Maintenance Dept. Record Book (2017-2021).*



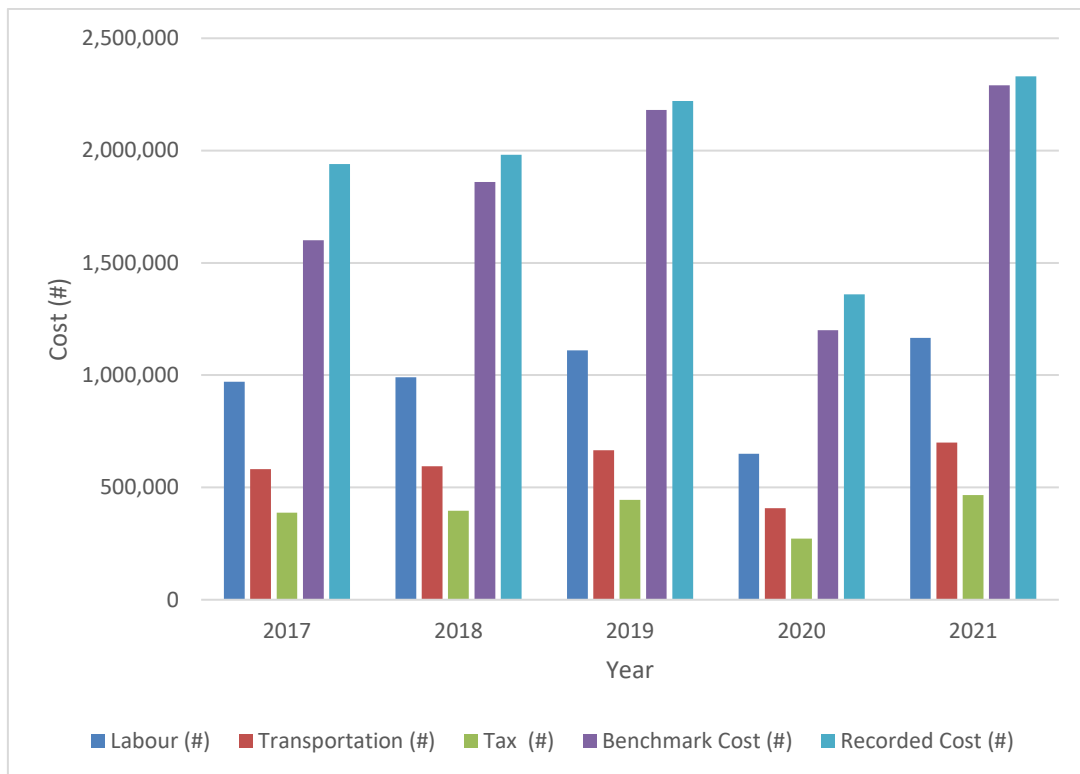
**Fig 4.4: Machine Downtime and Benchmark for Medium Line (0.063 Inches).**  
*Source: Maintenance Dept. Record Book (2017-2021).*



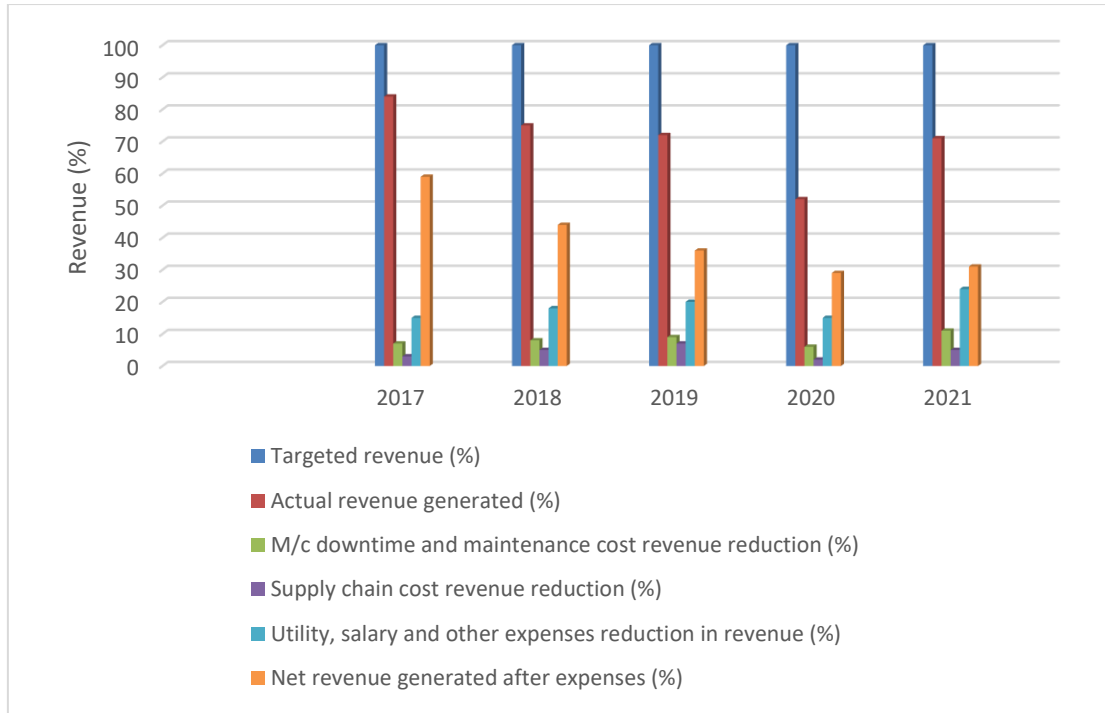
**Fig 4.5: Machine Downtime and Benchmark for Thick Line (0.125 Inches).**  
*Source: Maintenance Dept. Record Book (2017-2021).*



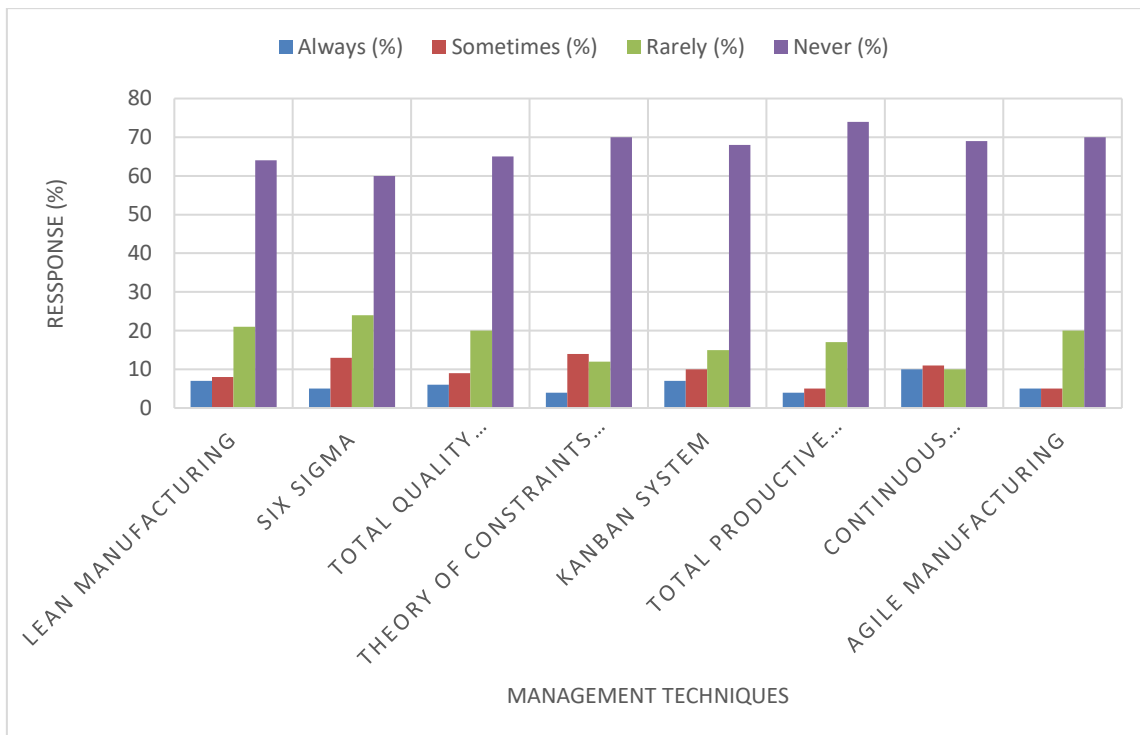
**Fig 4.6: Summary of annual cost of machine maintenance.**  
*Source: Procurement and Maintenance Rec. Dept. (2017-2021)*



**Fig4.7: Summary of the Supply to the Major Dealers from 2017 - 2021**  
*Source: Procurement Record Book*

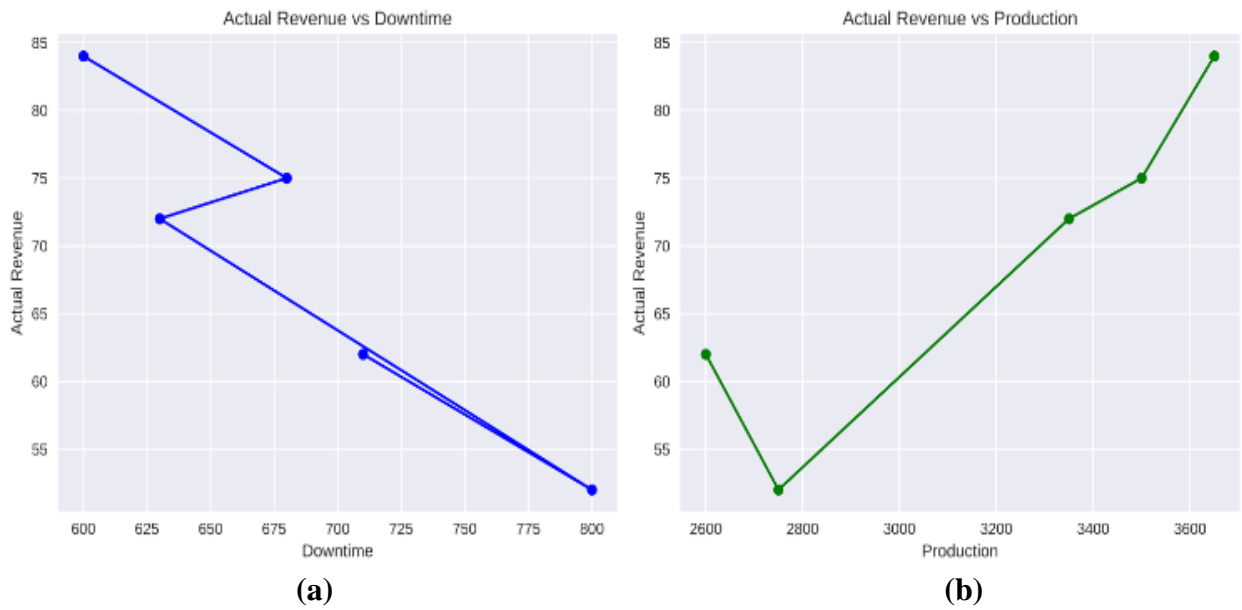


**Fig 4.8: Annual Revenue and Expenses Summary (2017-2021)**  
*Source: Authors computation from the company's available data*

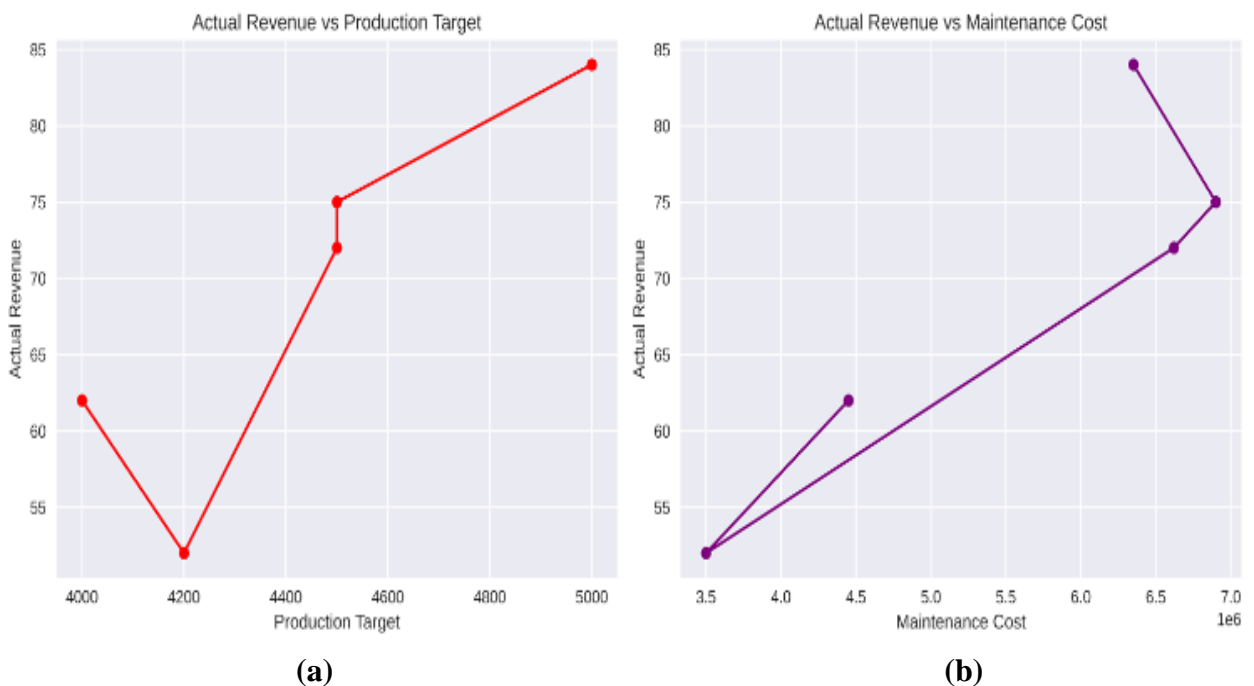


**Fig 4.9: Manufacturing Techniques Knowledge Response from the Staff**  
*Source: Questionnaire*

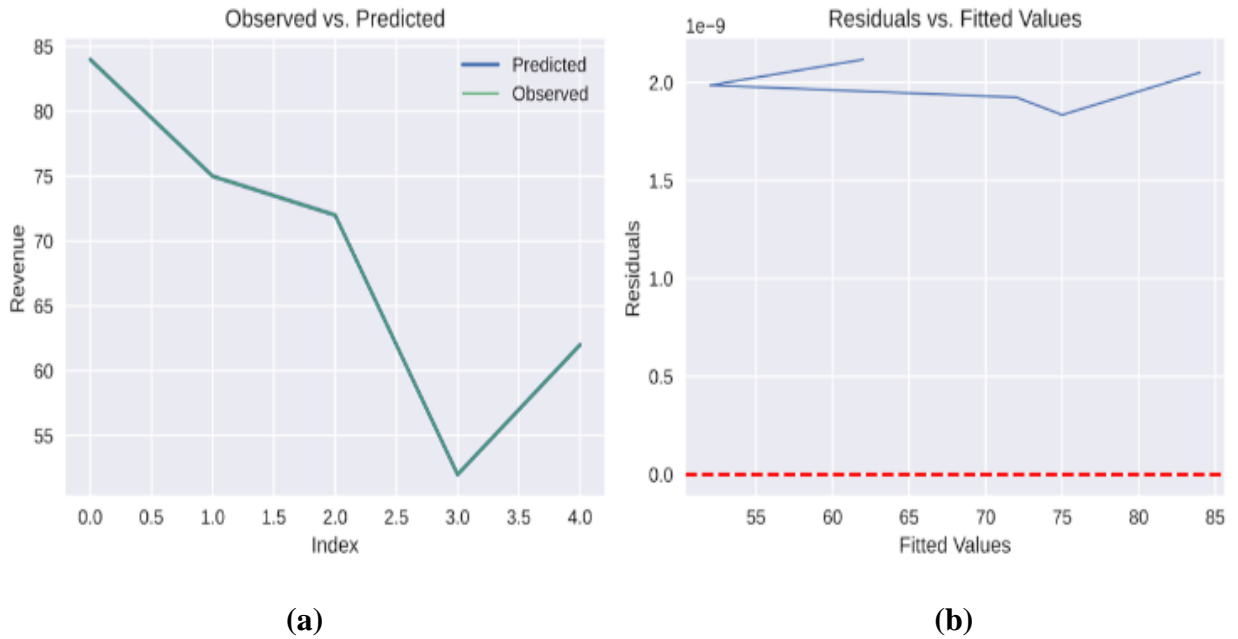
### 4.1.2 Model Result Presentation



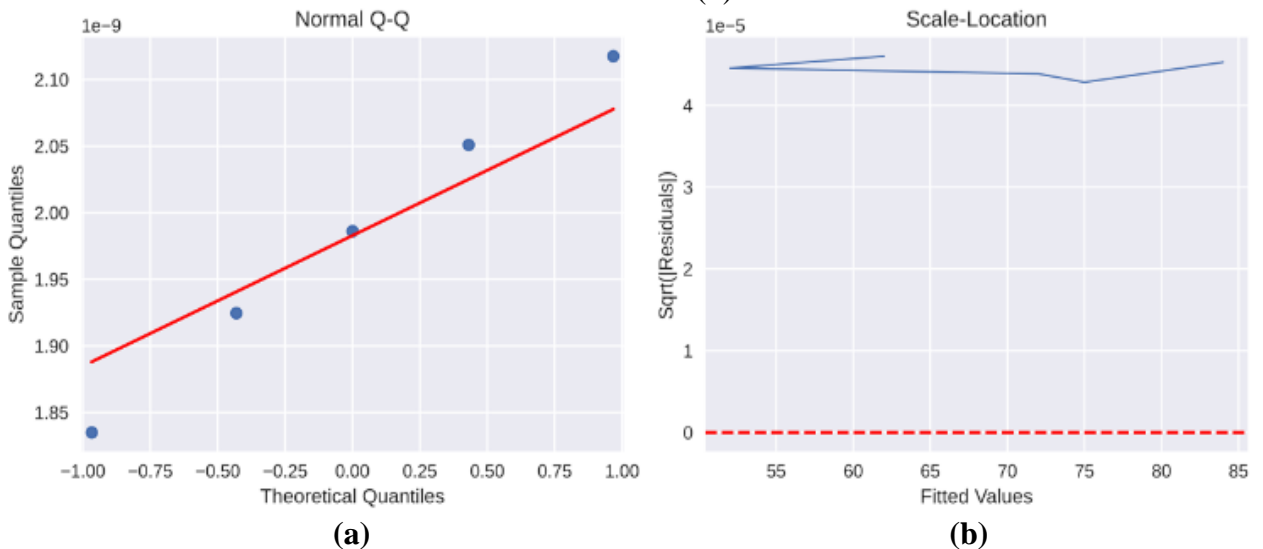
**Fig 4.10:** Model Graphical Representation of Actual Revenue vs. Downtime (a) and Actual Revenue vs. Production (b).



**Fig 4.11:** Model Graphical Representation of Actual Revenue vs. Production Target(a) Actual Revenue vs. Maintenance Cost (b).



**Fig 4.12:** Model Graphical Representation of Observed vs. Predicted Revenue(a) Residuals vs. Fitted Values (b).



**Fig 4.13:** Model Graphical Representation of Normal Q-Q (a) and Scale-Location (b) Plot.

### 4.1.3 Strategic Management Techniques (Lean Manufacturing)

**Table 4.1:** Maintenance and Quality Control Protocols for Different Roofing Sheet Production Lines

Production Line 1 (0.025 Inches Roofing Sheet)				
Machine	Persistent	Breakdown	Corrective Action	Preventive Action
Roller	Material Misalignment	Once a month	Adjust alignment, replace damaged parts	Regular maintenance, training for operators
Cutting	Blade Dullness	Twice a week	Sharpen blades, replace if necessary	Scheduled blade maintenance, blade quality checks

Coating	Uneven Coating Thickness	Once every 2 weeks	Calibrate equipment, monitor coating consistency	Regular inspections, preventive calibration
<b>Production Line 2 (0.063 Inches Roofing Sheet)</b>				
Roller	Material Jamming	Once a week	Clear jams, inspect conveyor belts	Implement material flow control, belt maintenance
Cutting	Inaccurate Cuts	Twice a month	Adjust cutting settings, maintain cutting blade	Regular calibration, blade replacement schedule
Coating	Coating Spillage	Once every 3 weeks	Clean spills, check nozzle alignment	Nozzle maintenance, training for spill response
<b>Production Line 2 (0.125 Inches Roofing Sheet)</b>				
Roller	Material Warping	Once every 2 weeks	Adjust rollers, inspect moisture content	Monitor material quality and moisture control
Cutting	Blade Chipping	Once a month	Replace damaged blade, check cutting alignment	Regular blade inspection, sharpening schedule
Coating	Irregular Staining	Once every 3 weeks	Adjust coating settings, clean nozzles	Regular equipment calibration, nozzle maintenance

**Table 4.2:** The Company Affected Eight Deadly Waste Type (*Defect*) and Lean Technique Proposed Remedies

S/N	Issues	Remedy
1	Shortage of Material: i. because there seemed to be no accurate knowledge on the availability of parts. ii. chaos erupted on a sudden realization that some parts were in short supply.	<b>Emphasize accurate stock keeping and incorporate Kanban in the working process, regularly updating to prevent information gaps.</b>
2	Low maintenance culture: i. longer production time per unit manufactured. ii. Tendency for defect occurrence is very high with aging equipment.	<b>Foster a preventive maintenance culture to reduce costs associated with reprocessing; Consider equipment replacement.</b>
3	Power Outage: i. Due to a power outage during production. ii. Materials not completely processed were taken to the next stage. iii. Inadequate technical know-how.	<b>Install solar power or a standby plant, along with an electrical generator supported by UPS/inverter for any scheduled production time; Provide more training on product development.</b>

**Table 4.3:** The Company Affected Eight Deadly Waste Type (*Inventory*) and Lean Technique Proposed Remedies

S/N	Issues	Remedy
1	Inconsistent Record Keeping: i. No interest in record keeping. ii. Material spill, defect, and re-do operations are not properly accounted for.	<b>Foster a culture of company auditing; Implement a computerized database to prevent errors associated with manual or paper recording.</b>
2	Overloading/Overstocking: i. Anticipated request for a product causes overstocking. ii. Fear of being stocked out and trying to meet urgent demand. iii. Due to stocks held for quality inspection to avoid sending defective products to the customer.	<b>Produce based on order; Inform customers about waiting periods before delivery; Maintain smaller stock levels.</b>
3	Inconsistent Record Keeping: i. No interest in record keeping. ii. Material spill, defect, and re-do operations are not properly accounted for.	<b>Instill a culture of company auditing; Implement a computerized database to prevent relapses associated with manual or paper recording.</b>

**Table 4.4:** The Company Affected Eight Deadly Waste Type (*Transportation*) and Lean Technique Proposed Remedies

S/N	Issues	Remedy
1	Unnecessary Transportation: i. Excessive movement of materials within the facility.	<b>Streamline material flow through a systematic layout.</b>
2	Poor layout causing frequent material handling.	<b>Minimize internal transportation through better planning.</b>
3	Lack of a systematic transportation plan.	<b>Optimize transportation routes and utilize lean principles to reduce unnecessary movement.</b>

**Table 4.5:** The Company Affected Eight Deadly Waste Type (*Overproduction*) and Lean Technique Proposed Remedies

S/N	Issues	Remedy
1	Communication Gap: i. Assumptions based on previous orders. ii. Absence of Kanban system. iii. Production aimed at taking advantage of low exchange rates for increased profits when rates rise.	<b>To foster a customer-centric approach, products should be manufactured based on customer orders, emphasizing post-service follow-up for customer insights. Implementing Kanban is crucial to prevent over and underproduction.</b>
2	No Kanban: i. Absence of enforced Kanban leads to incorrect output. ii. Unrequested product stocking consumes space and results in product deformation.	<b>Assign personnel for information gathering, addressing customer requests, and collecting feedback to ensure effective Kanban utilization.</b>
3	Product Hoarding: i. Extended stay of goods in the warehouse. ii. A significant number of stocked products recycled due to defects.	<b>Prioritize customer satisfaction over profit-seeking by focusing on timely product delivery and quality control measures. More focus should be on customer satisfaction than profiteering.</b>

**Table 4.6:** The Company Affected Eight Deadly Waste Type (*Waiting*) and Lean Technique Proposed Remedies

S/N	Issues	Remedy
1	Change Over Time: i. Lots of cleaning before the next shift. ii. non-standardized changeover time. iii. Supervisors' late coming and inability to discipline their team. iv. Lackadaisical attitude to work.	<b>Reduce debris produced during the production process; Implement regular cleaning schedules; Introduce improved manufacturing methods.</b>
2	Power Outage: i. Lost time due to generator faults. ii. Scarcity of diesel and administrative faults in diesel purchase allocation.	<b>Strengthen arrangements for the production process; Establish a set allocation for diesel and ensure timely issuance of all prerequisites for a steady power supply per production period.</b>
3	Unavailability of Personnel: i. Company understaffed to save costs. ii. Negligence and tardiness among the staff.	<b>Adequate staffing saves time and costs; Top management should install greater discipline.</b>

**Table 4.7:** The Company Affected Eight Deadly Waste Type (*Excess Processing*) and Lean Technique Proposed Remedies

S/N	Issues	Remedy
1	Faulty Machinery: i. Machine malfunction causing wastages. ii. Cost-saving measures leading to inefficient aging equipment.	<b>Embrace a maintenance culture; Invest in new and efficient equipment.</b>
2	Nonchalance to Duty: i. Individual overconfidence in the manufacturing process. ii. Monotony.	<b>Install more discipline; Rotate staff to prevent the growth of monotonous tendencies.</b>
3	Faulty Machinery: i. Machine malfunction causing wastages. ii. Cost-saving measures leading to inefficient aging equipment.	<b>Prioritize maintenance culture; Consider investing in new equipment.</b>

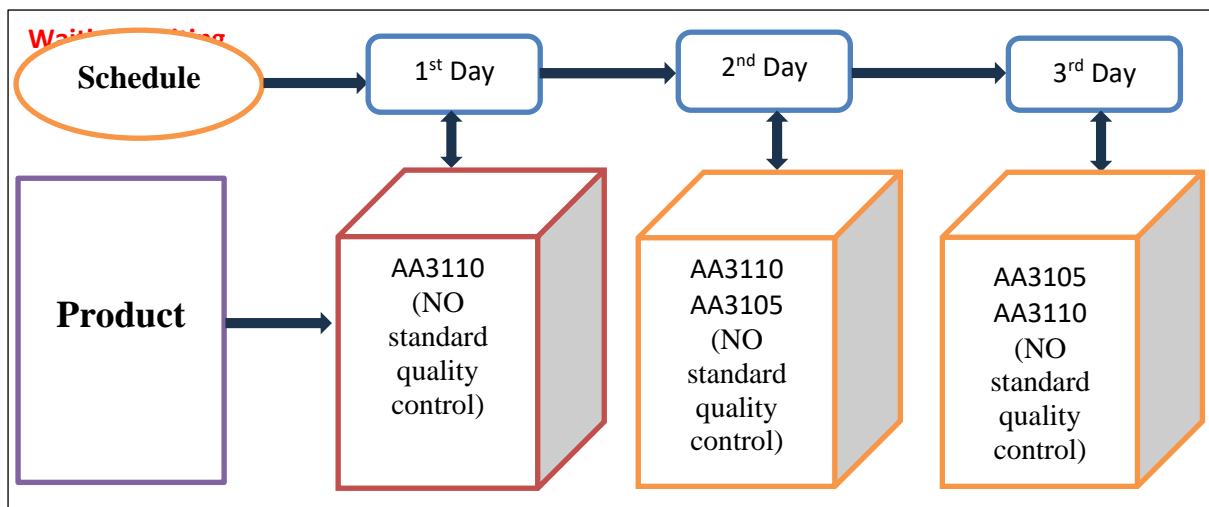
**Table 4.8:** The Company Affected Eight Deadly Waste Type (*Non-Utilized Talented and Skilled Workers*) and Lean Technique Proposed Remedies

S/N	Issues	Remedy
1	i. technical know-how in major production processes such as furnace heating and cold milling was poor. ii. Nepotism was evident. iii. No freedom to express views. iv. Little or no training sessions.	<b>Provide incentives for personnel with brilliant ideas; Ensure the right person for the job is chosen based on merit; Encourage an open and inclusive environment for expressing views; Implement comprehensive and regular training sessions.</b>
2	i. Lack of Standardization in Production Processes. ii. Inadequate Quality Control Measures. iii. Insufficient Monitoring of Machine Settings.	<b>Standardize production processes; Strengthen quality control measures; Implement robust monitoring systems for machine settings.</b>
3	i. Inadequate Cross-Training of Personnel. ii. Lack of Proper Inventory Management.	<b>Cross train personnel for flexibility in roles; Improve inventory management</b>

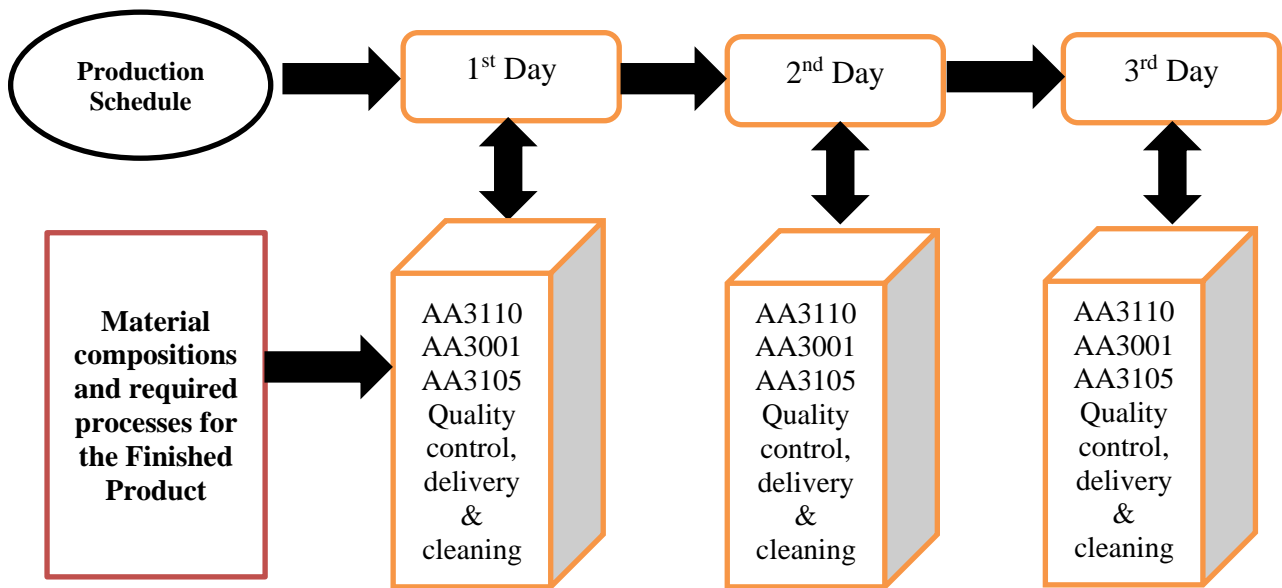
	iii. Insufficient Communication Between Production Stages.	<b>practices; Enhance communication channels between production stages.</b>
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**Table 4.9:** The Company Affected Eight Deadly Waste Type (*Motion*) and Lean Technique Proposed Remedies

S/N	Issues	Remedy
1	Low Awareness of Kanban: i. No training. ii. No teamwork and no written job instruction.	<b>Provide lean training on the usage and importance of Kanban; Implement teamwork and create written job instructions.</b>
2	Low Staff Strength: i. Trying to save costs due to salary payments. ii. Less hands for different attention-needing sectors of the manufacturing process.	<b>Employ the required number of staff for various crucial positions; Ensure an adequate workforce for each aspect of the manufacturing process.</b>
3	i. Inadequate Utilization of Equipment. ii. Unorganized Workplace Layout. iii. Lack of Visual Management Systems.	<b>Optimize equipment usage; Organize and streamline the workplace layout; Implement effective visual management systems for better efficiency.</b>



**Fig 4.14:** Long Established Production Style of the Aluminum Rolling Mill Company



**Fig 4.15:** The Heijunka Lean Tool Effect in the Production Schedules.

**Table 4.10: Current Takt time of the production process of the Company**

Item	Symbol	Units	Value
Time per shift	$T_s$	<i>secs</i>	6774.45
Break	$B$	<i>secs</i>	564.3
Time available	$A_t$	<i>secs/shift</i>	6213.33
Total customer demand	$D$	<i>units</i>	94.05
Number of working days	$n$	<i>days</i>	25
Number of shifts	$s$	-	2
Customer requirement per shift	$C$	<i>units/shift</i>	1.968
Additional value-adding activity	$V_{ad}$	<i>secs</i>	0
Takt time	$TK$	<i>secs</i>	515.01

*Source: Authors computation from the company's available data*

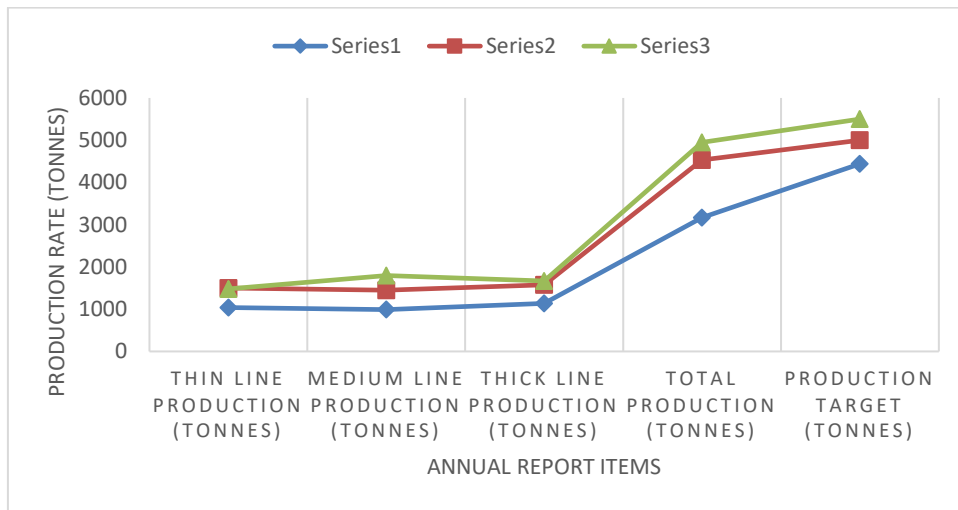
**Table 4.11: Future Takt time of the production process of the Company**

Time per shift	$T_s$	<i>secs</i>	6774.57
Break	$B$	<i>secs</i>	564.3
Time available	$A_t$	<i>secs/shift</i>	4555.62
Total customer demand	$D$	<i>units</i>	94.05
Number of working days	$n$	<i>days</i>	25

Number of shifts	<i>s</i>	-	2
Customer requirement per shift	<i>C</i>	<i>units/shift</i>	1.968
Additional value-adding activity	<i>Vad</i>	<i>secs</i>	28.2
Takt time	<i>TK</i>	<i>secs</i>	370.86

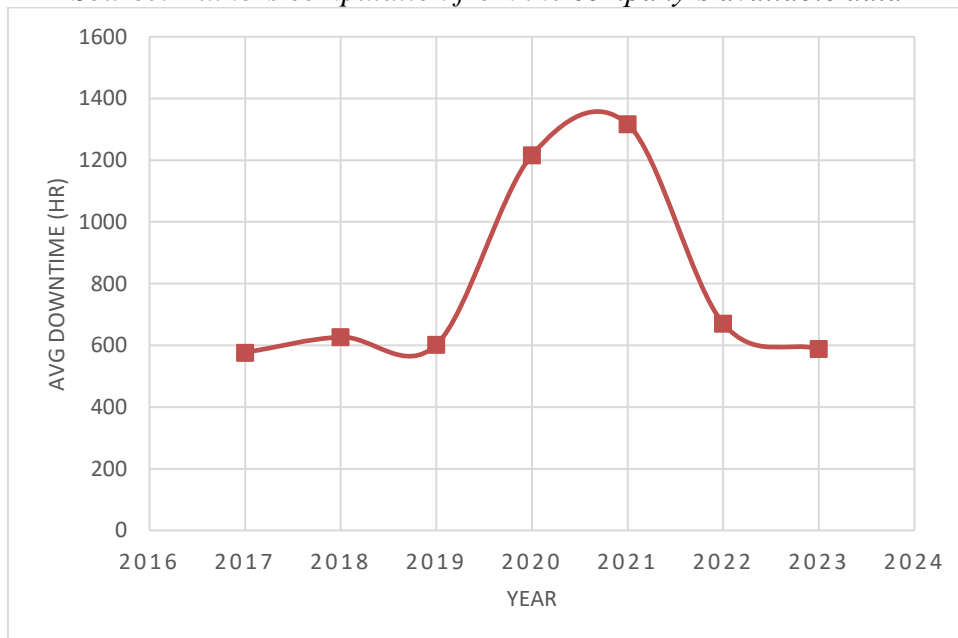
Source: Authors computation from the company's available data

#### 4.1.4 Comparison of the effect of the applied techniques



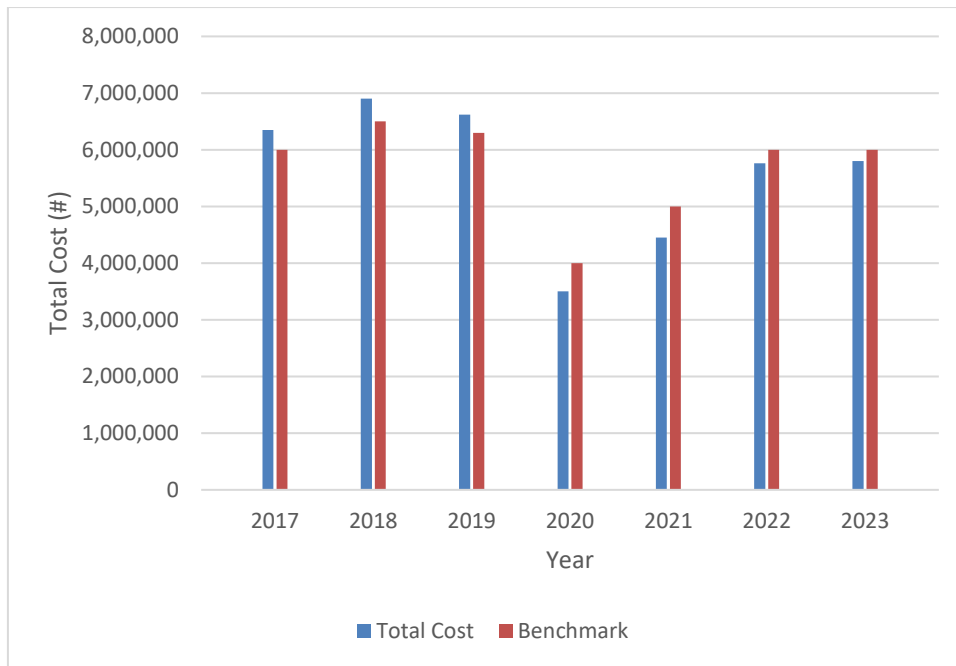
**Fig 4.16:** Average production rate comparison before (2017 – 2021) and after (2022 & 2023).

Source: Authors computation from the company's available data



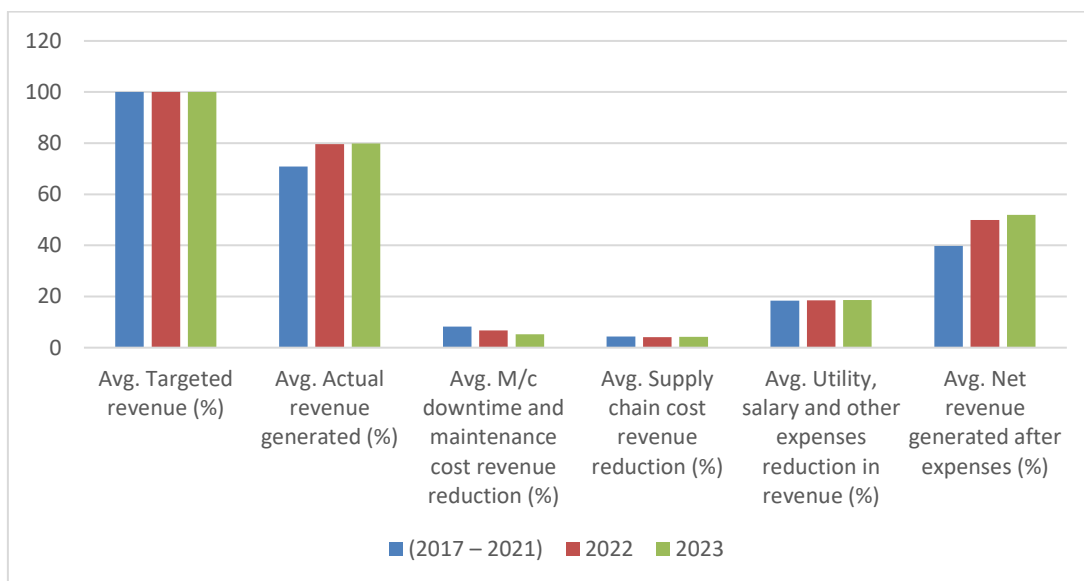
**Fig 4.17:** Average machine downtime comparison before (2017 – 2021) and after (2022 - 2023).

Source: Authors computation from the company's available data



**Fig 4.18:** Machine cost maintenance comparison before (2017 – 2021) and after (2022 & 2023).

*Source: Authors computation from the company's available data*



**Fig 4.19:** Revenue generation comparison before (2017 – 2021) and after (2022 & 2023).

*Source: Authors computation from the company's available data*

## 4.2 Discussion

### 4.2.1 Data Collection and Analysis Discussion

Figure 4.1 illustrates the production rates for thin, medium, and thick lines from 2017 to 2021, alongside the total production and production targets. Significantly, there is a noticeable decline in total production from 3,650 tons in 2017 to 2,600 tons in 2020, representing a 28.8% decrease. The production target also dropped from 5,000 tons in 2017 to 4,000 tons in 2021, indicating a 20% reduction. This decline highlights the need for critical evaluation of the root causes of the constant drop on the production challenges and the need for optimized strategies to enhance productivity and meet targets.

Figure 4.2 presents the survey responses identifying various challenges impacting productivity. Machine downtime consistently remains a significant issue, peaking at 32% in 2018. The COVID-19 pandemic caused a substantial disruption, reflected in the 35% response rate in 2020. Management issues and raw material shortages also significantly impacted productivity across the years, with management issues peaking at 25% in 2019. The IPOB sit-at-home orders notably affected productivity in 2021, accounting for 30% of the responses. These findings underscore the diverse and evolving challenges faced by the company, necessitating strategic interventions to mitigate these impacts.

Figure 4.3 – 4.5 illustrates the downtime in hours for various machines from 2017 to 2021 respectively in their various roofing thickness. Notably, the benchmark line remains consistently high at around 2500 hours, indicating a target or average downtime that most machines significantly underperform against. Over the years, there is a visible trend of decreasing downtime for most machines, but this reduction is not entirely positive. For instance, the downtime for the decoiler machine dropped from 200 hours in 2017 to 150 hours in 2021, representing a 25% reduction. However, this drop in 2020 can be attributed to the

COVID-19 pandemic, which led to reduced operational hours and workforce availability. Similarly, the hydraulic press saw a substantial decrease from 180 hours in 2017 to 100 hours in 2021, marking a 44.44% drop, and the embossing machine showed a significant improvement, with downtime reducing from 170 hours in 2017 to 90 hours in 2021, a 47.06% decrease. The drop in 2021 is largely due to the IPOB sit-at-home order every Monday in Southeast Nigeria, which disrupted regular operations.

These reductions in downtime, while seemingly positive, highlight the impact of external negative factors rather than improvements in operational efficiency. To address these issues and optimize machine performance, it is crucial to implement robust optimization techniques. These could include predictive maintenance to anticipate and prevent machine failures, workforce training to ensure efficient machine handling, and strategic planning to mitigate the impact of external disruptions. By focusing on these optimization strategies, the organization can achieve genuine improvements in machine downtime, aligning more closely with the benchmark and enhancing overall productivity.

Figure 4.6 reveals the distribution of maintenance costs across different machines from 2017 to 2021. The total annual maintenance cost for all machines shows a decreasing trend. For instance, the cost for the De-Coiler Machine dropped by approximately 25% over the period, and the Roll Forming Machine saw a reduction of about 20%. However, this reduction in maintenance costs does not reflect a positive trend. The significant decrease in costs in 2020 and 2021 is primarily due to the economic distress caused by the COVID-19 pandemic and the IPOB sit-at-home declaration every Monday, which severely affected the company's operations. The total maintenance costs decreased from ₦7,000,000 in 2017 to ₦5,000,000 in 2021, reflecting an overall reduction of approximately 28.6%. This highlights the need for instigation and introduction of optimization techniques to improve machine reliability and production efficiency despite external economic challenges.

Figure 4.7 shows the distribution of various costs associated with supply, including labor, transportation, tax, benchmark cost, and recorded cost. The data reveals a fluctuating trend in these costs over the five-year period. Notably, there is a significant reduction in costs in 2020 and 2021. For instance, labor costs decreased from over ₦1,000,000 in 2019 to approximately ₦800,000 in 2020, and transportation costs saw a reduction from about ₦500,000 in 2019 to around ₦300,000 in 2020. This reduction in costs, while seemingly beneficial, is primarily due to the economic distress caused by the COVID-19 pandemic and the IPOB sit-at-home declaration every Monday, which severely impacted the company's supply chain and overall productivity. The benchmark and recorded costs, which are critical for evaluating supply efficiency, also reflect a downward trend during these years. This highlights the need for investigation and introduction of optimization techniques to improve supply chain resilience and efficiency despite external economic challenges. Addressing these issues proactively can help the company mitigate the negative impacts and ensure a more stable and efficient supply process.

Figure 4.8 highlights the gap between targeted revenue and actual revenue generated over the five-year period. It also depicts the reductions in revenue due to machine downtime and maintenance costs, supply chain cost reductions, and other expenses such as utility and salary. The consistently lower actual revenue compared to the targeted revenue indicates a significant underperformance. In 2017, the actual revenue generated was around 70%, whereas the targeted revenue was close to 95%. This trend continues through 2021, showing persistent shortfalls in meeting revenue targets. The reductions in revenue due to machine downtime, maintenance costs, and supply chain issues further exacerbate the problem, reflecting inefficiencies in the company's operations. Notably, the year 2020 and 2021 saw a marked decrease in revenue, correlating with the economic distress caused by the COVID-19 pandemic and the IPOB sit-at-home declaration.

These negative impacts necessitate the investigation and introduction of optimization techniques to enhance productivity and reduce costs. By addressing these inefficiencies, the company can work towards closing the gap between targeted and actual revenue, ultimately improving overall financial performance.

Figure 4.9 presents the staff's responses regarding their knowledge and implementation of various management and production techniques which includes lean manufacturing, six sigma, total quality management (TQM), theory of constraints (TOC), Kaban system, total productivity maintenance (TPM), continuous improvement (kaizen), and agile manufacturing. The results highlight a notable gap in familiarity and application of these tools by the staff. Specifically, lean manufacturing, TQM, and agile manufacturing exhibit a lower level of understanding, with most respondents indicating either rare or no knowledge. This indicates a need for targeted training and awareness programs to enhance staff proficiency in these tools. These findings underscore the importance of educational initiatives to foster a comprehensive understanding of production maintenance and management principles among the staff.

#### **4.2.2 The Applied Model Results Discussion**

Figure 4.10 (a) shows actual revenue vs. downtime of the collected data on the applied model which illustrates negative correlation between downtime and revenue. As downtime increases from 600 to 800 hours, actual revenue drops significantly from 84% to 52%. This underscores the importance of minimizing machine downtime to prevent revenue losses. Figure 4.10 (b) shows the trend of actual revenue vs. production of the collected data on the applied model which demonstrates a positive correlation between production rates and revenue. When production increases from 2600 to 3650 tons, actual revenue rises from 52% to 84%. This highlights the necessity of optimizing production rates to enhance revenue generation. By focusing on reducing machine downtime and increasing production efficiency, the company

can achieve higher revenue, aligning closely with the benchmarks and targets set for the years 2017 to 2021.

Figure 4:11 (a) presents the actual revenue vs. production target trend which depicts a positive correlation between production targets and actual revenue. As the production target increases from 4000 to 5000 tons, the actual revenue also rises from 59% to 84%. This indicates that setting higher production targets can drive the company towards better revenue generation, provided the targets are realistic and achievable. Figure 4: 11 (b) presents the actual revenue vs. maintenance cost which shows the relationship between maintenance costs and actual revenue. It reveals that up to a certain point, higher maintenance costs correlate with higher revenue, as seen with maintenance costs rising from 3.5 million to 7 million and revenue increasing from 29% to 84%. This suggests that investing in maintenance to ensure machine reliability and efficiency can positively impact revenue by reducing downtime and enhancing productivity.

Together, these figures highlight that optimizing production targets and investing in maintenance are crucial strategies for improving the company's productivity and revenue. Effective management of these factors can help mitigate the decline in productivity and support sustained financial performance.

Figure 4.12 (a) presents the observed vs. predicted revenue of the applied model which shows the comparison between the observed actual revenue and the predicted revenue from the regression model. The close alignment of the observed and predicted values indicates that the model is accurately capturing the relationship between the variables affecting revenue. This validation suggests that the model can reliably be used to forecast revenue based on production and downtime data. Figure 4.12 (b) presents the residuals vs. fitted values of the applied model which illustrates the residuals (the differences between observed and predicted values) plotted

against the fitted values. The residuals are close to zero, indicating that there is minimal error in the predictions. This suggests that the regression model provides a good fit for the data, with a high R-squared value demonstrating strong explanatory power.

Together, these figures validate the effectiveness of the regression model in optimizing the company's productivity and revenue. The accurate predictions and minimal residuals indicate that the model can be used to make informed decisions to mitigate factors causing the decline in productivity, such as excessive downtime and inefficient maintenance practices.

Figure 4.13 (a) presents the Normal Q-Q Plot of the applied model which illustrates the quantiles of the residuals against the theoretical quantiles from a normal distribution. The points closely follow the red line, indicating that the residuals are approximately normally distributed. This supports the validity of the regression model assumptions, confirming that the errors are normally distributed, which is essential for reliable inference and prediction. Figure 4.13 (b) illustrates the Scale-Location Plot (or Spread-Location Plot), this graph displays the square root of the standardized residuals against the fitted values. The residuals are evenly spread along the range of fitted values, indicating homoscedasticity (constant variance of residuals). This is another key assumption of regression analysis, showing that the model performs consistently across different levels of the predicted values.

These diagnostic plots confirm that the regression model is well-fitted and reliable for predicting the revenue of the aluminum roofing sheet company. The normality of residuals and homoscedasticity indicate that the model can be used to make accurate and consistent predictions. This supports the positive impact of optimizing downtime and maintenance costs, as validated by the regression model, in improving the company's productivity and revenue.

### **4.2.3 Recommendation of Strategic Maintenance (Lean Techniques)**

Table 4.1 presents maintenance and quality control protocols for the different roofing sheet lines thereby captured some major machine like the roller, cutting, and coating on their persistent issues during production and the times they normally fail, then suggested strategic corrective and preventive actions for the problem.

Table 4.2 – 4.9 presents some of the managerial, production, and supply chain mechanism issues affecting the company's productivity negatively and established some remedies to curb the issues. The strategic solutions utilized the eight deadly wastes lean management techniques thereby, grouping the issues in eight common wastes in a typical production company (motion, non-utilization of talented and skilled workers, defects, inventory, transportation, overproduction, waiting and excess processing), then suggest some good remedies for each item.

Figure 4.14 presents the improved schedule method of the company, implementing quality control to counter waiting issue on the production line as presented in Figure 4.15, this strategy was developed from the application of Heijunka lean manufacturing element for daily production planning process of the respective specification of sheets. Although this will require some amount of discipline to pull off, but it will benefit the organization as products created will be based on customer demand and will give enough time for quality inspections per day on the three products produced and set for delivery, minimizing work-in-process, lead time, and improving delivery response to the consumer.

Table 4.10 - 4.11 provide an analysis of the current and future takt time for the production process of the company. The current takt time, calculated as 515.01 seconds, reflects the time available per unit required to meet customer demand. The future takt time, projected at 370.86 seconds, is based on optimizing the production process through the incorporation of additional

value-adding activities. Presented in Table 4.10, the time per shift, breaks, and total available time are considered, along with customer demand, working days, shifts, and the resulting takt time. The customer requirement per shift ( $C$ ) is calculated at 1.968 units per shift. Notably, no additional value-adding activity ( $Vad$ ) is factored in.

Table 4.11 envisions the future Takt time, where a new value-adding activity is introduced. The time available is adjusted, considering this additional activity, resulting in a reduced Takt time of 370.86 seconds. This reflects a more efficient production process geared towards meeting customer demand with optimized time utilization. The proposed changes aim to enhance productivity and align the production pace with customer requirements, contributing to overall process improvement.

#### **4.2.4 Comparison of the effect of the applied techniques**

Figure 4.16 shows a noticeable increase in production rates from the previous years (2017-2021) to the current years (2022-2023), with total production rising from 3,170 tons to 4,950 tons, indicating a 56.2% increase. This enhancement is attributed to the application of optimization models and lean management tools. Figure 4.17 reveals a reduction in average machine downtime from a high of 1,316.67 hours in 2021 to 588.34 hours in 2023, representing a 55.3% decrease, showcasing improved operational efficiency. Additionally, Figure 4.18 illustrates a decline in machine maintenance costs, which, although peaking at 6,900,000 in 2018, have stabilized closer to the benchmark of 6,000,000 in 2022 and 2023, indicating better cost control. Finally, Figure 4.19 highlights an increase in net revenue generated after expenses, with a rise from 39.8% in the previous years to 51.9% in 2023, reflecting a 30.4% improvement, underscoring the positive financial impact of the implemented strategies.



## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATIONS

#### 5.1 Conclusion

The study comprehensively addressed the challenges facing JAMBAZ Aluminum Roofing Sheet Company by integrating advanced data analytics and lean manufacturing techniques. Analysis of production data from 2017 to 2021 revealed significant insights into operational inefficiencies and external disruptions, such as machine downtime and pandemic-related constraints, which collectively contributed to a 28.8% decline in total production and a 20% reduction in production targets over the period. The application of predictive maintenance through regression models demonstrated a substantial improvement in operational efficiency, notably reducing average machine downtime by 55.3% from 1,316.67 hours in 2021 to 588.34 hours in 2023.

Moreover, strategic maintenance initiatives, including lean manufacturing tools like Heijunka and Takt Time, facilitated a 56.2% increase in total production from 3,170 tons to 4,950 tons between 2017-2021 and 2022-2023 periods, respectively. This enhancement not only optimized production schedules but also aligned production rates more closely with market demand, resulting in a 30.4% improvement in net revenue generation after expenses. Cost management strategies further stabilized machine maintenance costs around the benchmark figure of ₦6,000,000 in 2022-2023, showcasing effective financial control amid economic uncertainties.

#### 5.2 Recommendations

- i. Implement predictive maintenance strategies to pre-emptively address machine failures and minimize downtime.
- ii. Enhance digital skills training among the workforce to optimize the utilization of production technologies and improve efficiency.
- iii. Adopt lean manufacturing principles such as Heijunka and Takt Time to streamline production processes, reduce waste, and enhance productivity.
- iv. Invest in continuous improvement initiatives to foster a culture of innovation and efficiency within the organization.

- v. Strengthen supply chain resilience to mitigate the impact of external disruptions and ensure consistent production output.

### **5.3 Contribution to Knowledge**

- i. The study contributed to knowledge by integrating quantitative data analysis with qualitative insights, providing a holistic understanding of productivity challenges.
- ii. The development and application of the PRO model demonstrated its effectiveness in optimizing production and revenue, offering a structured approach for performance enhancement.
- iii. By recommending lean manufacturing principles, the study highlighted their role in improving operational efficiency and reducing costs in manufacturing settings.
- iv. Recommendations for strategic maintenance practices provided actionable insights into enhancing machine reliability and minimizing production disruptions.

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## Appendix

**Table 1: Company's Production Rates and Targets**

Year	Thin Line Production (tonnes)	Medium Line Production (tonnes)	Thick Line Production (tonnes)	Total Production (tonnes)	Production Target (tonnes)
2017	1200	1150	1300	3650	5000
2018	1150	1100	1250	3500	4500
2019	1100	1050	1200	3350	4500
2020	900	850	1000	2750	4200
2021	850	800	950	2600	4000

*Source: Inventory and Production Record Dept.*

**Table 2: Factors Affecting Productivity of JAMBAZ Aluminium Roofing Sheet Company (2017-2021).**

Year	Machine Downtime	Supply Chain Route	COVID-19 Pandemic	IPOB Sit-at-Home	Management Issues	Raw Material Shortage	Inflation
2017	24%	21%	1%	1%	20%	15%	18%
2018	26%	20%	1%	1%	18%	15%	19%
2019	20%	23%	1%	1%	23%	12%	20%
2020	10%	12%	40%	1%	9%	8%	20%
2021	20%	8%	5%	35%	8%	5%	19%

**Table 3: Machine Downtime and Benchmark for Thin Line (0.025 Inches).**

Machine	2017	2018	2019	2020	2021	Benchmark
Decoiler	50	55	52	120	130	2088
Roll Forming	80	85	83	140	150	2088
Cut-to-Length	60	65	63	130	140	2088
Hydraulic Press	70	75	72	140	150	2088
Embossing	55	60	57	120	130	2088
Corrugation	75	80	78	140	150	2088
Shearing	65	70	68	130	140	2088
Edge Trimming	50	55	53	120	130	2088
Coating	45	50	48	110	120	2088
Annealing Furnace	85	90	88	150	150	2088

*Source: Maintenance Record Book*

**Table 4: Machine Downtime and Benchmark for Medium Line (0.063 Inches)**

Machine	2017	2018	2019	2020	2021	Benchmark
Decoiler	45	50	48	110	120	2088
Roll Forming	70	75	73	130	140	2088
Cut-to-Length	55	60	58	120	130	2088
Hydraulic Press	65	70	68	130	140	2088
Embossing	50	55	52	110	120	2088
Corrugation	70	75	73	130	140	2088
Shearing	60	65	63	120	130	2088

Edge Trimming	45	50	48	110	120	2088
Coating	40	45	43	100	110	2088
Annealing Furnace	75	80	78	140	150	2088

*Source: Maintenance Record Book*

**Table 5: Machine Downtime and Benchmark for Thick Line (0.125 Inches)**

Machine	2017	2018	2019	2020	2021	Benchmark
Decoiler	40	45	43	100	110	2088
Roll Forming	60	65	63	120	130	2088
Cut-to-Length	50	55	53	110	120	2088
Hydraulic Press	60	65	63	120	130	2088
Embossing	45	50	47	100	110	2088
Corrugation	65	70	68	130	140	2088
Shearing	55	60	58	120	130	2088
Edge Trimming	40	45	43	100	110	2088
Coating	35	40	38	90	100	2088
Annealing Furnace	70	75	73	140	150	2088

*Source: Maintenance Record Book*

**Table 6: Summary of annual cost of maintenance on machine**

year	Decoiler Machine	Roll Forming Machine	Cut-to-Length Machine	Hydraulic Press Machine	Embossing Machine	Corrugation Machine	Shearing Machine	Edge Trimming Machine	Coating Machine	Annealing Furnace	Total Cost (₺)	Yearly Benchmark (₺)
2017	500,000	800,000	600,000	700,000	550,000	750,000	650,000	500,000	450,000	850,000	6,350,000	6,000,000
2018	550,000	850,000	650,000	750,000	600,000	800,000	700,000	550,000	500,000	900,000	6,900,000	6,500,000
2019	520,000	830,000	630,000	720,000	570,000	780,000	680,000	530,000	480,000	880,000	6,620,000	6,300,000
2020	300,000	400,000	350,000	400,000	300,000	400,000	350,000	300,000	250,000	450,000	3,500,000	4,000,000
2021	400,000	500,000	450,000	500,000	400,000	500,000	450,000	400,000	350,000	500,000	4,450,000	5,000,000

*Source: Procurement and Maintenance Rec. Dept. (2017-2021)*

**Table 7: Summary of the Supply to the Major Dealers from 2017 - 2021**

Year	Labour (#)	Transportation (#)	Tax (#)	Benchmark Cost (#)	Recorded Cost (#)
2017	970,000	582,000	388,000	1,600,700	1,940,000
2018	990,400	594,240	396,160	1,860,300	1,980,800
2019	1,110,450	666,270	444,180	2,180,550	2,220,900
2020	650,225	408,135	272,090	1,200,300	1,360,450
2021	1,165,430	699,258	466,172	2,290,600	2,330,860

*Source: Procurement Record Book*

**Table 8: Annual Revenue and Expenses Summary (2017-2021)**

Year	Targeted revenue (%)	Actual revenue generated (%)	M/c downtime and maintenance	Supply chain cost revenue reduction (%)	Utility, salary and other expenses	Net revenue generated
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			cost revenue reduction (%)		reduction in revenue (%)	after expenses(%)
2017	100	84	7	3	15	59
2018	100	75	8	5	18	44
2019	100	72	9	7	20	36
2020	100	52	6	2	15	29
2021	100	71	11	5	24	31

*Source: Authors computation from the company's available data*

**Table9: Lean Manufacturing Tools Knowledge Response from the Staff**

Management Techniques	Always (%)	Sometimes (%)	Rarely (%)	Never (%)
Lean Manufacturing	7	8	21	64
Six Sigma	5	13	24	60
Total Quality Management (TQM)	6	9	20	65
Theory of Constraints (TOC)	4	14	12	70
Kanban System	7	10	15	68
Total Productive Maintenance (TPM)	4	5	17	74
Continuous Improvement (Kaizen)	10	11	10	69
Agile Manufacturing	5	5	20	70

*Source: Questionaries*

**Table 10:** Average machine downtime comparison before (2017 – 2021) and after (2022 - 2023).

YEAR	2017	2018	2019	2020	2021	2022	2023
<b>AVG. M/C Downtime</b>	576.67	626.67	602.00	1216.67	1316.67	670.68	588.34

*Source: Authors computation from the company's available data*

**Table 4.11:** Machine cost maintenance comparison before (2017 – 2021) and after (2022 & 2023).

Year	Total Cost	Benchmark
2017	6,350,000	6,000,000
2018	6,900,000	6,500,000
2019	6,620,000	6,300,000
2020	3,500,000	4,000,000
2021	4,450,000	5,000,000
2022	5,760,080	6,000,000
2023	5,800,000	6,000,000

*Source: Authors computation from the company's available data*

**Table 12:** Revenue generation comparison before (2017 – 2021) and after (2022 & 2023).

Previous Years	Avg. Targeted revenue (%)	Avg. Actual revenue generated (%)	Avg. M/c downtime and maintenance cost revenue reduction (%)	Avg. Supply chain cost revenue reduction (%)	Avg. Utility, salary and other expenses reduction in revenue (%)	Avg. Net revenue generated after expenses (%)
(2017 – 2021)	100	70.8	8.2	4.4	18.4	39.8
2022	100	79.6	6.7	4.1	18.5	50
2023	100	79.9	5.2	4.2	18.6	51.9

*Source: Authors computation from the company's available data*

**Table 13:** Average production rate of the company from the previous years and current years

Year	Thin Line Production (tonnes)	Medium Line Production (tonnes)	Thick Line Production (tonnes)	Total Production (tonnes)	Production Target (tonnes)
Previous	1040	990	1140	3170	4440
2022	1500	1450	1580	4530	5000
2023	1480	1800	1670	4950	5500

*Source: Authors computation from the company's available data*

**Table 14:** Questionary sample on management techniques knowledge among the JAMBAZ staff

S/N	Technique Type	Questions	Response
1	<b>Lean Manufacturing</b>	How familiar are you with Lean Manufacturing principles?  Can you explain the concept of 5S in Lean Manufacturing?  Have you participated in any Kaizen events? If so, what was your role?	
2	<b>Six Sigma</b>	Do you have any Six Sigma certification (e.g., Yellow Belt, Green Belt)?  Can you describe the DMAIC process?  Have you used any Six Sigma tools (e.g., Fishbone Diagram, Control Charts)?	
3	<b>Total Quality Management (TQM)</b>	What are the core principles of Total Quality Management? How does TQM affect production quality in our company? Can you provide an example of a TQM initiative you were involved in?	

<b>4</b>	<b>Theory of Constraints (TOC)</b>	Can you identify the main constraints in our production line? How do you manage bottlenecks in your daily work? Have you used TOC to improve process efficiency? How?	
<b>5</b>	<b>Kanban System</b>	Are you familiar with the Kanban system used in our production? How does Kanban help in managing our production workflow? Have you suggested any improvements to our Kanban system?	
<b>6</b>	<b>Total Productive Maintenance (TPM)</b>	What are the benefits of Total Productive Maintenance? How do you ensure preventive maintenance is carried out effectively? Have you been involved in TPM initiatives? If yes, what was your contribution?	
<b>7</b>	<b>Continuous Improvement (Kaizen)</b>	How do you practice continuous improvement in your daily tasks? Can you provide an example of a successful Kaizen project you participated in? What suggestions do you have for improving our continuous improvement efforts?	

*Source: Author's Design*

## MODEL CODES

```
import matplotlib.pyplot as plt
import numpy as np
import statsmodels.api as sm
# Sample data (replace with actual data)
actual_revenue = np.array([84, 75, 72, 52, 62]) downtime = np.array([600, 680, 630, 800, 710])
# Example total downtime values
production = np.array([3650, 3500, 3350, 2750, 2600])
production_target = np.array([5000, 4500, 4500, 4200, 4000])
maintenance_cost = np.array([6350000, 6900000, 6620000, 3500000, 4450000])
# Add constant to the independent variable set for the regression model
X = np.column_stack((downtime, production, production_target, maintenance_cost))
X = sm.add_constant(X)
# Fit the regression model
model = sm.OLS(actual_revenue, X).fit()
predicted_revenue = model.predict(X) residuals = actual_revenue - predicted_revenue
# Plotting
fig, axes = plt.subplots(2, 2, figsize=(12, 8))
# Observed vs. Predicted
```

```

Plotaxs[0, 0].scatter(actual_revenue, predicted_revenue, color='blue')
axs[0, 0].plot([min(actual_revenue), max(actual_revenue)], [min(actual_revenue),
max(actual_revenue)], color='red', linewidth=2) axs[0, 0].set_xlabel('Observed Revenue')
axs[0, 0].set_ylabel('Predicted Revenue') axs[0, 0].set_title('Observed vs. Predicted Revenue')
# Residuals vs. Fitted Values
Plotaxs[0, 1].scatter(predicted_revenue, residuals, color='blue') axs[0, 1].axhline(y=0,
color='red', linestyle='dashed', linewidth=2) axs[0, 1].set_xlabel('Predicted Revenue') axs[0,
1].set_ylabel('Residuals') axs[0, 1].set_title('Residuals vs. Fitted Values')
# Normal Q-Q
Plotsm.qqplot(residuals, line='45', fit=True, ax=axs[1, 0]) axs[1, 0].set_title('Normal Q-Q
Plot') # Scale-Location
Plotaxs[1, 1].scatter(predicted_revenue, np.sqrt(np.abs(residuals))), color='blue') axs[1,
1].axhline(y=np.sqrt(np.mean(np.abs(residuals))), color='red', linestyle='dashed',
linewidth=2) axs[1, 1].set_xlabel('Predicted Revenue') axs[1, 1].set_ylabel('Square Root of
Standardized Residuals') axs[1, 1].set_title('Scale-Location Plot')
plt.tight_layout()
plt.show()

```