# EVALUATION OF PERFORMANCE IMPROVEMENT USING MATLAB SIMULATION IN A TILE PRODUCTION FACILITY

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A PROJECT SUBMITTED TO THE DEPARTMENT OF PRODUCTION
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SUPERVISOR: ENGR. DR. O. IKPONMWOSA EWEKA

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# CERTIFICATION

This is to certify that this project work was carried out by Ajibade John Adewale with matriculation number ENG2002644 in the department of Production Engineering, University of Benin, Benin City, Edo State, Nigeria.

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# DEDICATION

We dedicate this project to the Almighty God, whose grace, wisdom, and strength have seen me through the course of this academic journey.

To my beloved parents, Mr. & Mrs. Ajibade for their unwavering support, encouragement, and sacrifices throughout our education. Your love has been my foundation.

To my supervisor, Engr. Dr. O. Ikponmwosa Eweka for his guidance, patience and invaluable contributions toward the success of this work and also to all my lecturers.

To my brothers Ajibade Peter, Ajibade Jeremiah, and also to Kolawale Oluwafunmilayor and to my Harmony Church family, Bro. Marvellous Obase, GC Kelvin, SWC Paulina, Sis. Gift Ihaza and others.

We also dedicate this work to every student striving for excellence and growth in the field of engineering and technology. May this serve as a source of inspiration and knowledge.

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My profound gratitude goes to God Almighty the giver of life, for His mercies and grace which kept us throughout our period of stay in school.

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To everyone who contributed, directly or indirectly, to the success of this research, thank you.

# ABSTRACT

This study aimed to evaluate and enhance the efficiency of a tile production facility in Benin City, Nigeria through MATLAB-based simulation and optimization. The research was conducted in response to persistent challenges in local tile manufacturing, including high energy consumption, low throughput, and significant defect rates. The study sought to develop a robust simulation model capable of analyzing the plant's operational performance, identifying critical inefficiencies, and proposing optimization strategies that align with real-world production constraints.

The methodology involved systematic data collection on machine utilization, downtime, energy consumption, and defect levels from the facility. These data were used to design a MATLAB simulation model that replicated the major stages of tile manufacturing mixing, pressing, drying, glazing, and firing. The model evaluated baseline performance conditions and tested multiple optimization scenarios such as load balancing, batch size adjustment, and preventive maintenance scheduling. The simulation outputs were analyzed to determine their operational feasibility within existing equipment and workforce limitations.

The results showed substantial improvements across key production metrics. Daily output increased by approximately 20%, machine utilization rose from 85% to 92%, and defect rates decreased from 6.0% to 3.5%. Energy consumption per tile dropped by 7%, contributing to a 4.8% reduction in production cost. Financial projections indicated a 37% increase in monthly gross profit following optimization. These findings confirm that MATLAB simulation provides a cost-effective and practical approach for improving efficiency, product quality, and profitability in Nigeria’s tile manufacturing sector.

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# NOMENCLATURE

MATLAB: Matrix Laboratory

MTBF: Mean Time Between Failures

MTTR: Mean Time to Repair

kWh: Kilowatt-hour

DOE: Design of Experiments

OEE: Overall Equipment Effectiveness

GA: Genetic Algorithm

O&M: Operations and Maintenance

QC: Quality Control

kW: Kilowatt

PLC: Programmable Logic Controller

SCADA: Supervisory Control and Data Acquisition

OPEX: Operational Expenditure

CAPEX: Capital Expenditure

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background of Study

The ceramic tile industry is an essential component of the construction and building materials sector, providing durable, aesthetic, and functional surfaces for residential and industrial applications. In Nigeria, the increasing rate of urbanization and infrastructural development has significantly raised the demand for ceramic and porcelain tiles. However, despite this market expansion, the majority of local manufacturers still struggle with inefficiencies, high operational costs, and inconsistent product quality due to limited process automation and inadequate technological integration (Obanor & Udofia, 2021).

Historically, tile production in Nigeria began in the late 1980s through government-supported import substitution initiatives, but most plants relied on manual or semi-automated production lines. Facilities such as West African Ceramics, BN Ceramics, and Time Ceramics later emerged, yet the core production systems remained labour-intensive, with poor energy utilization and limited digital process control (Akinyemi et al., 2020). As of 2023, local plants are estimated to operate at less than 65% capacity utilization, with energy costs accounting for up to 25–35% of total production expenditure (National Bureau of Statistics, 2023). This historical lag in adopting digital technologies continues to affect competitiveness against imported tiles from China, Italy, and Spain.

Globally, simulation technologies have become standard tools for optimizing industrial systems. Simulation allows engineers to evaluate alternative process configurations, identify bottlenecks, and improve operational performance without physical experimentation (Law & Kelton, 2015). In developed economies, simulation-based process modeling using tools such as MATLAB, Arena, and Simulink has led to measurable gains in throughput, energy reduction, and quality consistency (Sánchez et al., 2019). In contrast, sub-Saharan Africa—and Nigeria in particular—has experienced limited adoption due to financial constraints, low technical capacity, and minimal collaboration between academia and industry (Nwachukwu & Ezeokonkwo, 2021).

MATLAB, as a high-level engineering environment, offers extensive capabilities for simulating and analyzing dynamic production systems. In tile manufacturing, it can model key process stages such as raw material preparation, drying, and kiln firing, allowing engineers to evaluate factors like temperature profiles, energy use, and material flow. When applied effectively, MATLAB bridges the gap between traditional, experience-based production and data-driven manufacturing optimization. For small and medium enterprises (SMEs), this creates a pathway toward gradual industrial digitalization, cost reduction, and improved global competitiveness.

## 1.2 Problem Statement

Tile manufacturers in Benin City and other parts of Nigeria face recurring challenges related to low process efficiency, excessive energy consumption, material wastage, and high defect rates. Many production systems are manually operated, poorly monitored, and depend on operator intuition rather than data-driven control. For instance, studies show that defective or substandard tiles account for between 5–10% of total output, while energy inefficiencies raise production costs by up to 20% compared to international benchmarks (Adeoye et al., 2023). Such inefficiencies translate into reduced profitability and limited competitiveness in both domestic and export markets.

Although simulation tools like MATLAB have been successfully employed in optimizing ceramic processes globally, their application in Nigeria's tile industry remains rare. The gap is not only technological but structural, caused by:

- Limited technical know-how in simulation modeling and data integration.
- Financial barriers associated with software licensing and model implementation.
- Institutional constraints, including weak collaboration between academic researchers and manufacturing firms.

Consequently, process improvements in local tile facilities are often based on trial-and-error methods, leading to inconsistent outcomes and production downtime. There is a critical need to quantify the performance inefficiencies, model the production process using simulation tools, and test possible optimization strategies that reflect real-world limitations such as machine capacity, workforce availability, and energy cost.

## 1.3 Aim and Objectives of the Study

### 1.3.1 Aim of the Study

The aim of this study is to evaluate and enhance the performance improvement using MATLAB simulation in a tile production facility.

### 1.3.2 Objectives of the Study

To achieve the aim of this study, the following objectives will be pursued;

i. Collect quantitative data on production performance, machine utilization, downtime, and energy consumption from the case study facility.

ii. Develop a MATLAB-based simulation model representing the major stages of the tile production process.

iii. Simulate and analyze current performance indicators such as throughput, defect rate, energy usage, and cost per unit.

iv. Introduce optimization scenarios such as load balancing, batch size adjustment, and maintenance scheduling and assess their simulated effects on key performance metrics.

v. Evaluate measurable performance improvements (e.g., ≥10% increase in throughput, ≥5% reduction in energy cost, and ≥3% improvement in product yield) while considering operational constraints like equipment capacity and labour limits.

## 1.4 Scope of the Study

This study focuses on evaluating and improving the performance of a tile production facility located in Benin City, Edo State, Nigeria. It involves modeling major stages of the production process such as raw material preparation, pressing, drying, and firing using operational data collected directly from the selected facility. The analysis will be conducted through MATLAB and Simulink simulations to assess current performance levels, identify inefficiencies, and test improvement strategies. While the primary emphasis is on digital simulation and analysis, the study may also include partial or full implementation of selected improvements at the facility, depending on feasibility and management consent.

## 1.5 Significance of the Study

Tiles production facility in Nigeria faces operational challenges that hinder productivity, inflate production costs, and limit its competitiveness in both local and regional markets. By applying MATLAB-based simulation tools to evaluate and optimize its production processes, the study offers practical, data-driven solutions tailored to the real-world constraints of the facility. The outcomes are expected to improve process efficiency, reduce waste, enhance product quality, and ultimately strengthen the company's profitability and sustainability.

The study holds broader relevance to the local economy and society. Improved efficiency in tile production can lead to more affordable building materials, supporting the housing and construction sectors in Benin City and surrounding areas. As construction becomes more cost-effective, access to quality infrastructure improves, indirectly contributing to urban development and social well-being. Additionally, increased production efficiency can enable local manufacturers to meet higher demand, expand operations, and create more jobs for residents, thus boosting economic growth and reducing unemployment.

From an academic standpoint, this study offers a hands-on opportunity to apply core principles of production systems design, process analysis, and industrial simulation in a real manufacturing environment. Through this project, the student not only strengthens technical skills in MATLAB and process modeling but also develops a deeper understanding of how engineering tools can solve real-life industrial problems.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Overview of Tiles Production

The production of tiles is a critical aspect of the construction materials industry, offering both functional and aesthetic benefits to buildings and infrastructures. As urbanization and real estate development continue to accelerate in Nigeria and other developing countries, the demand for high-quality, locally manufactured tiles has significantly increased (Adebayo, 2019). This rise in demand places considerable pressure on tile manufacturing companies to optimize their production processes, minimize operational costs, and maintain consistent product quality. In this context, performance evaluation and process improvement have become essential goals for manufacturers aiming to remain competitive and sustainable.

Historically, tile manufacturing has relied on mechanical systems and human labor to handle critical tasks such as raw material preparation, pressing, drying, glazing, and firing. These operations are highly sensitive to variations in process parameters, and any inefficiency such as energy loss, inconsistent moisture content, or machine downtime can adversely affect the quality of the final product and increase production costs (Oladele *et al*., 2020). This makes it necessary to develop frameworks that allow manufacturers to model and optimize their production systems in a cost-effective and non-intrusive way.

Simulation tools have emerged as powerful means of analyzing and improving manufacturing processes across various industries. In particular, the application of digital simulation in ceramic and tile production enables engineers to predict process behavior, identify inefficiencies, and evaluate improvement strategies without interrupting physical operations (Sánchez *et al*., 2019). Among the available tools, MATLAB stands out due to its ability to integrate data analysis, dynamic modeling, and control system design within a single platform. When applied effectively, MATLAB simulations can provide valuable insights into system bottlenecks, cycle time variations, and energy consumption trends thereby guiding informed decisions for performance improvement.

Despite the global shift toward digital process optimization, Nigerian tile manufacturers—especially small- and medium-scale producers have yet to fully adopt such tools in their operations. This is due to limited technical expertise, inadequate infrastructure, and a lack of localized studies that demonstrate the practical benefits of simulation in real-world settings (Nwachukwu & Ezeokonkwo, 2021).

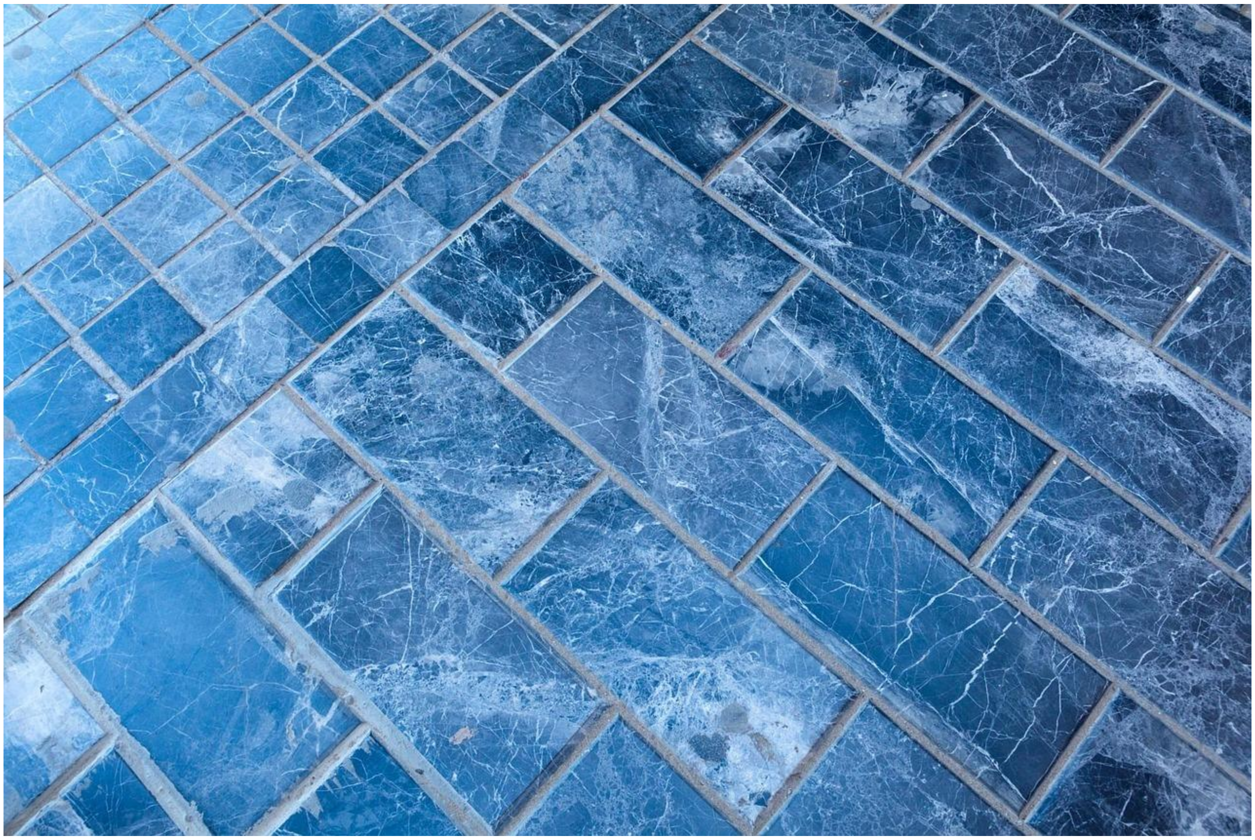


*Plate 2.1 - Ceramic tile [Phalbon Nigerian Enterprise Benin]*

## 2.2 Tiles and its production history in Nigeria

Tiles, in the context of building and civil construction, refer to flat, thin, and rigid units produced from materials such as clay, porcelain, stone, glass, or cement. These units are manufactured in standardized shapes and sizes and used for covering floors, walls, and ceilings, as well as for decorative and protective purposes. In both residential and industrial settings, tiles serve critical roles in providing aesthetics, durability, hygiene, thermal resistance, and ease of maintenance. Their application ranges from indoor areas such as kitchens and bathrooms to external spaces including terraces, walls, and even facades in modern architecture.

*Plate 2.2 - Porcelain tile [Phalbon Nigerian Enterprise Benin]*

*Plate 2.3 - Stone tile [Phalbon Nigerian Enterprise Benin]*

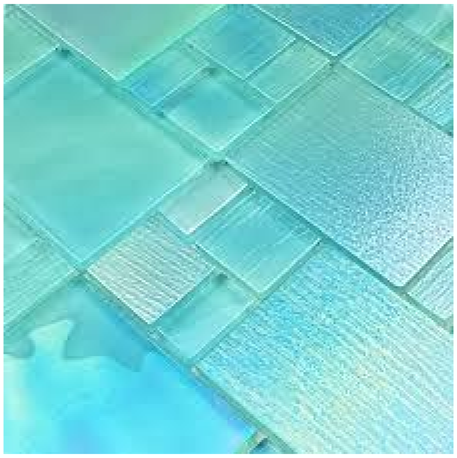


*Plate 2.4 - Glass tile [Phalbon Nigerian Enterprise Benin]*

In Nigeria, tile production and usage have grown considerably over the last few decades, driven by a rising demand for modern housing, commercial buildings, and urban infrastructure. Prior to the 1980s, the majority of ceramic and vitrified tiles used in the country were imported from Europe, the Middle East, and more recently, from China. Local production was nearly non-existent, constrained by poor industrial infrastructure, limited technical know-how, and the absence of robust raw material processing systems. However, with the gradual implementation of import substitution policies, industrial incentives, and increased demand for affordable housing, local tile manufacturing began to take root (Akinyemi *et al*., 2020).

There are various types of tiles produced and utilized in Nigeria today, each differentiated by material composition, production method, surface finish, and application. Ceramic tiles remain the most widely used due to their relatively low production cost and versatility. These tiles are produced from natural clay mixed with additives, shaped through pressing or extrusion, and hardened through firing in a kiln. Ceramic tiles are typically glazed to enhance surface properties such as color, water resistance, and abrasion resistance. Porcelain tiles, in contrast, are made from finer and denser clay, fired at higher temperatures, which makes them more durable, less porous, and suitable for both indoor and outdoor high-traffic applications. They are commonly used in commercial and public buildings where strength and water resistance are essential (Hassan & Ogedengbe, 2018). Other notable categories include vitrified tiles, known for their glossy finish and low porosity, and cement-based tiles, which are still used in low-cost construction in peri-urban regions.

The process of tile manufacturing involves multiple critical stages. Raw materials such as kaolin, feldspar, quartz, and ball clay are first crushed, milled, and blended to achieve the desired chemical and physical properties. The mixture is then shaped using hydraulic presses or extrusion systems, followed by drying, glazing, and firing. The firing process is one of the most energy-intensive and technically demanding stages, often requiring temperatures above 1000°C. This sequence must be meticulously controlled to prevent defects such as warping, cracking, and poor adhesion of the glaze layer. In industrial practice, efficiency and uniformity across these stages determine both the quality and cost-competitiveness of the final product.

*Plate 2.5 - Cement tile [Phalbon Nigerian Enterprise Benin]*

In Nigeria, the availability of essential raw materials for tile production presents a significant advantage. Clay deposits suitable for ceramic processing are found in abundance in states like Ogun, Kogi, Kaduna, and Edo. Benin City, the capital of Edo State, is particularly well-positioned due to its proximity to feldspar and kaolin deposits, which are key components in both ceramic and porcelain tile manufacturing. This raw material availability, coupled with a growing local market, has attracted small- and medium-scale manufacturers to set up production facilities in and around the city.

However, despite this geographical advantage, tile production in Benin City and other parts of Nigeria remains technologically underdeveloped. Many existing facilities operate with outdated machinery, semi-automated systems, and manual quality control processes. These factors contribute to low production yields, high defect rates, inconsistent product quality, and excessive energy consumption (Obanor & Udofia, 2021). One of the primary challenges is the lack of integration between process design and performance monitoring, which leads to inefficiencies that go uncorrected over time. Unlike large-scale foreign manufacturers that use advanced tools such as Supervisory Control and Data Acquisition (SCADA) systems and automated kilns, most local producers rely on human supervision and experience-based decision-making.

An additional challenge is the fluctuating cost of energy, which makes kiln operations particularly expensive. Tile firing consumes a significant amount of thermal energy, and with Nigeria’s erratic power supply, many manufacturers resort to diesel or gas-fired burners. These costs directly affect profitability and product pricing, reducing the competitiveness of local tiles against imported alternatives. Moreover, the inability to simulate or digitally test process improvements means that trial-and-error remains the dominant method of production optimization. This outdated approach not only increases production downtime but also discourages innovation and scalability.

In response to these challenges, there has been a growing interest in integrating simulation and modeling tools such as MATLAB and Simulink into production system design and optimization. These tools allow manufacturers and engineers to create digital models of the production process, simulate different operating conditions, and identify optimal configurations for maximizing output and minimizing cost. MATLAB-based simulations, for instance, can be used to model the drying curve of tiles, thermal energy consumption in kilns, mechanical stress during pressing, and production throughput under varying batch sizes (Adeoye *et al*., 2023). These models enable engineers to predict process behavior under different scenarios without disrupting actual operations.

The implementation of simulation in tile manufacturing is particularly promising in the Nigerian context, where resources are limited and efficiency is essential for survival in a competitive market. By using simulation tools, even small- and medium-scale producers can gain insights that previously required expensive experiments or external consultants. For instance, a tile production facility in Benin City could use MATLAB to simulate its drying and firing processes, identify excessive energy loss points, or optimize the material flow between workstations to reduce idle time. Such improvements, though minor in appearance, could lead to significant cost savings and enhanced product quality over time.

## 2.3 Overview of Tile Production Process

Tile production is a highly coordinated industrial operation involving a series of thermomechanical and chemical transformations designed to convert raw materials into strong, dimensionally stable, and aesthetically pleasing surface materials. This process, though seemingly straightforward, involves a wide range of engineering variables, each of which can influence the quality, cost, and speed of production. Understanding the full scope of the tile manufacturing process is crucial in identifying areas where inefficiencies may occur and where performance enhancements can be achieved using modern tools such as simulation software.

The tile production cycle begins with raw material selection and preparation. The most commonly used materials in ceramic and porcelain tile production include clay, feldspar, quartz, kaolin, and other aluminosilicate compounds. These raw materials must be carefully sourced and characterized based on their chemical composition, particle size distribution, and mineralogical properties. In Nigeria, particularly in regions such as Edo, Ogun, and Kogi states, these materials are abundant in natural deposits, but their unrefined state often requires processing to meet industrial specifications (Hassan & Ogedengbe, 2018). The materials are typically subjected to crushing and milling operations in which they are reduced to fine powders to ensure homogeneity and reactivity in later stages.

*Plate 2.6 - ATE 90 Spray Dryer [sacmi groups]*

Once adequately milled, the powdered mixture is blended with water and additives to create a slurry known as slip. This slip is then subjected to a drying process typically spray drying to remove excess moisture and produce uniform granules with consistent moisture content, which are suitable for pressing. In semi-automated plants such as those found in Benin City, spray drying may be substituted with manual drying or tray drying, which can be less efficient and more prone to inconsistency. These inconsistencies often lead to variations in green strength and shrinkage behavior, which in turn affect final product quality.

The next critical step in the tile production process is shaping, usually done by hydraulic pressing. Here, the granulated material is filled into molds and compressed under high pressure to form the desired tile shapes and thicknesses. The uniform application of pressure is essential to ensure dimensional accuracy, structural strength, and minimal internal stress. In many Nigerian facilities, the precision of this stage is often compromised by outdated equipment or inadequate process monitoring, which may result in warping or cracking during subsequent firing (Obanor & Udofia, 2021). For more advanced production lines, computer-controlled hydraulic presses allow for precise pressure settings and cycle times, thereby reducing variability.

*Plate 2.7 - Hydraulic Tile Press Machine [sacmi groups]*

Following shaping, the pressed tiles referred to as green tiles are subjected to a controlled drying process to eliminate residual moisture. If drying is not carefully managed, the tiles may develop cracks due to internal stress differentials. Industrial dryers are typically employed for this purpose, but in resource-limited settings, sun drying or simple kiln-based methods may still be in use. This stage is energy-intensive and time-sensitive; thus, it presents a critical target for performance optimization through simulation.

After drying, many tiles undergo a glazing process in which a glass-like coating is applied to their surface to enhance aesthetics and surface properties such as resistance to stains, abrasion, and chemicals. The glaze can be applied through various techniques including spray glazing, curtain coating, or screen printing. This is followed by the firing stage, which is one of the most energy-consuming and technically demanding phases. Tiles are fired at high temperatures, often between 1000°C and 1300°C, in continuous or batch kilns. The firing transforms the physical structure of the tile, vitrifying the body and bonding the glaze to the surface. The success of this transformation depends heavily on temperature uniformity, heating rate, and firing time. A deviation in any of these parameters can lead to defects such as bloating, pinholes, or glaze separation (Akinyemi *et al*., 2020).

In Nigerian factories, especially those operating on limited budgets, kiln operations are often manually controlled, with operators relying on visual inspection and experience to determine kiln conditions. This practice can result in inefficiencies in fuel usage, inconsistent product output, and extended downtime due to maintenance or corrective actions. This underscores the importance of introducing simulation-based control strategies that allow engineers to model thermal energy consumption, simulate temperature profiles, and predict product behavior under different firing conditions (Adeoye *et al*., 2023).

Once firing is completed, the tiles are cooled, sorted, and subjected to quality inspection. This may involve checking for visual defects, dimensional accuracy, water absorption, and mechanical strength. High-quality tiles are then packaged for distribution, while defective ones may be recycled or discarded, depending on the facility's waste management protocol.

Overall, tile production is a complex interplay of material science, thermal engineering, mechanical design, and process control. In the Nigerian context, especially within small and medium enterprises in cities like Benin, inefficiencies in this process are common and often go unaddressed due to the absence of real-time data, modern process monitoring tools, and simulation-based decision-making. The integration of MATLAB or other simulation platforms offers a significant opportunity to study the tile production process at a systems level. It allows for virtual testing of various process parameters, identification of bottlenecks, prediction of defect occurrences, and optimization of energy usage, all of which contribute to improved performance without the risks associated with real-time trial and error.

The application of such tools is not only timely but also necessary in Nigeria’s evolving industrial landscape, where manufacturers are under increasing pressure to reduce costs, improve quality, and remain competitive in both local and global markets. A well-modeled and simulated tile production process provides critical insights that can guide equipment upgrades, staff training, energy efficiency strategies, and quality assurance protocols, thereby transforming traditional tile manufacturing into a data-driven, performance-oriented system.

## 2.4 Simulation in Manufacturing Systems

Simulation in manufacturing refers to the use of virtual models to replicate and study real-world production systems, with the aim of analyzing their behavior under various conditions without physically altering the system. As manufacturing becomes increasingly complex due to the rising demand for customization, cost reduction, and time-to-market pressures, simulation has emerged as a vital tool for engineers and production managers in improving process efficiency, minimizing downtime, and supporting decision-making. It allows manufacturers to test process changes, new layouts, workflow configurations, or production schedules in a digital environment before implementation, thereby reducing risk and enabling data-driven optimization.

Historically, simulation has been used to address various manufacturing challenges, ranging from machine utilization and production line balancing to inventory control and quality assurance. By enabling the study of systems that involve randomness, human interaction, and machine behavior, simulation provides deep insight into the dynamic nature of production operations. This is particularly useful in discrete manufacturing settings such as tile production, where different stages including raw material handling, shaping, drying, glazing, and firing must be synchronized for efficient operation. In such environments, physical experiments to improve processes are costly, time-consuming, and sometimes disruptive to production. Simulation, therefore, provides a safe and effective alternative for experimentation and learning (Law & Kelton, 2015).

The core value of simulation lies in its ability to model the flow of materials, information, and energy through manufacturing systems. For instance, it can be used to determine bottlenecks within a production line by visualizing and analyzing where queues form, which machines are underutilized or overloaded, and how variations in demand affect production output. In tile manufacturing, this could involve simulating the effect of kiln temperature settings on firing time, analyzing the impact of moisture content on drying duration, or evaluating the energy consumption patterns of different process routes. Simulation also enables the integration of various performance parameters such as throughput, cycle time, defect rate, and energy efficiency into a unified model, thereby facilitating holistic decision-making (Banks *et al*., 2010).

A key advantage of simulation is that it allows the incorporation of variability and uncertainty, which are common in real manufacturing environments. Parameters such as machine breakdowns, variable operator efficiency, raw material inconsistency, and fluctuating order volumes can all be factored into simulation models. This leads to more realistic outcomes and enables proactive risk management. For example, a tile production facility in Benin City might face regular power fluctuations or variations in clay quality due to local sourcing. These irregularities, which can be difficult to analyze using traditional deterministic methods, can be effectively studied using stochastic simulation techniques. The ability to simulate "what-if" scenarios equip managers with foresight on how the system responds under adverse or alternative conditions, ultimately supporting resilient and agile manufacturing systems (Chryssolouris, 2006).

Modern simulation tools range from general-purpose programming environments such as MATLAB and Python to specialized software like Arena, Simul8, FlexSim, and AnyLogic. MATLAB, in particular, offers a powerful platform for modeling, simulation, and analysis of production processes due to its numerical accuracy, high computational efficiency, and integration with Simulink for dynamic system simulation. MATLAB's strength lies in its matrix-based architecture, which facilitates the representation of production data, process parameters, and control logic in an intuitive format. Engineers can write custom scripts to simulate workflows, optimize scheduling algorithms, monitor process variations, and generate visualizations of system performance over time (MathWorks, 2023).

For tile production, where heat and mass transfer processes play a significant role especially during drying and firing stages, MATLAB can be used to model the underlying physics through differential equations and simulate their effects on product quality and energy consumption. For example, by simulating the drying rate of ceramic tiles based on ambient temperature and material moisture content, engineers can determine the optimal drying conditions that minimize energy use and prevent product cracking. Furthermore, MATLAB's SimEvents toolbox can be applied to simulate discrete events such as machine operation cycles, material flow between workstations, and queuing delays in semi-automated production systems like those found in Nigerian tile factories. This level of flexibility enables manufacturers to fine-tune their operations based on both empirical data and predictive analytics (Adeoye *et al.*, 2023).

Despite its benefits, the adoption of simulation in Nigerian manufacturing industries especially among small- and medium-scale enterprises remains limited. Contributing factors include lack of technical expertise, insufficient awareness of simulation benefits, and the perceived cost of software acquisition and model development. Nonetheless, there is growing academic and industrial interest in leveraging simulation to overcome operational inefficiencies in sectors like ceramics, food processing, textiles, and metalworks. In the context of Benin City, where many tile producers still rely on manual operations and fragmented control systems, simulation presents a viable path toward digital transformation and sustainable production. It offers the potential to not only improve process control but also to guide capital investment, workforce planning, and production scaling.

### 2.4.1 MATLAB as a Simulation Tool in Engineering

MATLAB, which stands for Matrix Laboratory, is a high-performance programming environment developed by MathWorks that integrates computation, visualization, and programming in a user-friendly interface. It has become a fundamental tool in the field of engineering due to its powerful capabilities in numerical computation, algorithm development, data analysis, simulation, and model-based design. Originally developed for linear algebra and matrix computations, MATLAB has since evolved into a comprehensive technical computing language used across multiple branches of engineering, including mechanical, electrical, civil, chemical, and production engineering. Its applicability in simulation makes it particularly valuable for analyzing complex systems where theoretical models must be tested, refined, and optimized in a virtual environment before being implemented in real-world scenarios.

The versatility of MATLAB as a simulation tool lies in its ability to model dynamic systems using mathematical representations and simulate their behavior under various operational conditions. Engineers can use it to describe processes in the form of differential equations, transfer functions, or state-space representations and observe system responses without building physical prototypes. This approach significantly reduces cost, time, and material waste. In production engineering and manufacturing systems, MATLAB enables engineers to develop models of production lines, evaluate system bottlenecks, monitor resource utilization, optimize scheduling, and assess energy consumption patterns. These models allow for process improvement before applying changes on the factory floor, thus enhancing efficiency and minimizing disruptions (Mohammed & Al-Yaseen, 2021).

One of MATLAB's most widely adopted features is Simulink, a graphical environment for multi-domain simulation and model-based design. With Simulink, engineers can construct block-diagram models of dynamic systems and simulate real-time operations. This is especially useful in manufacturing environments where mechanical, thermal, and control subsystems must be integrated into a single cohesive model. For example, in a tile production facility, a simulation using Simulink can help predict how changes in kiln temperature profiles, material throughput, or drying time affect overall productivity and energy use. Such simulations provide data-driven insights that guide process redesign and optimization strategies (Gomez *et al*., 2019).

Another critical advantage of MATLAB is its extensive library of toolboxes, which offer specialized functions for various applications. The Control System Toolbox, Optimization Toolbox, and Statistics and Machine Learning Toolbox are frequently used in engineering simulations to tune parameters, optimize system behavior, and analyze data patterns. In production engineering, these capabilities are instrumental in conducting sensitivity analyses, quality control studies, and predictive modeling. MATLAB's integration with hardware and other software systems also makes it ideal for designing cyber-physical systems and implementing digital twins of physical processes (Ali *et al*., 2022).

In the Nigerian context, the adoption of MATLAB in engineering education and industrial research has grown steadily over the last decade. Its availability in many tertiary institutions and its compatibility with theoretical coursework have made it a core element in engineering training. However, its potential remains underutilized in the industrial sector, particularly in small- and medium-scale manufacturing firms, which often lack the expertise or awareness to adopt simulation-based approaches. Yet, as industries face growing pressure to reduce costs, improve product quality, and enhance operational efficiency, the role of simulation tools like MATLAB becomes increasingly indispensable. For instance, in tile production where thermal efficiency, batch processing, and defect control are major concerns, MATLAB offers a structured platform to simulate process dynamics, test control strategies, and perform root-cause analysis for process failures (Adeoye *et al*., 2023).

Moreover, MATLAB's capacity for real-time data visualization, model validation, and system identification ensures that it is not only a tool for academic experimentation but also a robust platform for industrial application. Engineers can collect operational data from sensors or programmable logic controllers (PLCs) within a manufacturing plant, feed them into MATLAB models, and simulate performance in real-time. This real-time feedback loop enables predictive maintenance, dynamic process adjustment, and enhanced decision-making. For a developing industrial environment like that of Benin City, where this study is focused, such capabilities can revolutionize the performance evaluation and upgrade of existing tile production facilities.

### 2.4.2 Application of MATLAB in Process Optimization

MATLAB, an acronym for Matrix Laboratory, is a powerful computing environment and programming platform widely employed across engineering disciplines for algorithm development, data analysis, system modeling, and numerical computation. In the context of industrial manufacturing, MATLAB offers a versatile and dynamic platform for simulating, analyzing, and optimizing production processes. Its built-in toolboxes and integration capabilities with simulation environments like Simulink make it particularly suitable for addressing the complexities of process optimization in resource-constrained environments, such as those found in many small- and medium-scale manufacturing facilities in Nigeria.

Process optimization involves the systematic adjustment of input variables, control parameters, and operating conditions to maximize output efficiency, product quality, and resource utilization while minimizing waste, downtime, and cost. In manufacturing systems such as tile production, optimization is critical because the process involves several interdependent variables including moisture content, firing temperature, cycle time, raw material composition, and machine throughput. Achieving optimal conditions manually is not only time-consuming but also prone to errors due to the variability and dynamic behavior of production processes. MATLAB addresses these limitations by allowing engineers to develop mathematical models that accurately describe the physical processes and simulate their behavior under different conditions without physically altering the system (Naikan & Bhattacharya, 2015).

One of MATLAB's most effective applications in process optimization lies in its ability to perform simulation-based design of experiments (DOE), sensitivity analysis, and multi-objective optimization. In ceramic and tile manufacturing, for example, MATLAB can be used to develop thermal models of the drying and firing stages, simulate the effect of temperature distribution in kilns, and analyze how changes in input variables affect the final product. By doing so, manufacturers can identify optimal setpoints that reduce energy consumption, minimize cracking or warping of tiles, and improve cycle times. MATLAB's optimization toolbox supports linear, nonlinear, and global optimization routines, enabling engineers to solve both constrained and unconstrained problems that arise in production environments (MathWorks, 2023).

In production environments where empirical data is available, MATLAB can also facilitate data-driven optimization through machine learning and statistical modeling. By analyzing historical process data, MATLAB can uncover patterns and correlations between input parameters and output quality, thus enabling predictive control strategies. For instance, regression models and neural networks built in MATLAB can be used to forecast tile failure rates or predict energy demand based on variations in batch size or material composition. This predictive capability empowers manufacturers to make proactive decisions and mitigate losses before they occur (Sharma *et al*., 2021).

Another valuable feature is MATLAB's integration with real-time systems and hardware, which allows the implementation of closed-loop control systems in production settings. Through real-time data acquisition and control simulation, engineers can use MATLAB to optimize parameters such as conveyor speed, material feed rate, and temperature profiles in response to live process feedback. This creates a dynamic production environment that is self-correcting and responsive to disturbances, ultimately improving overall equipment effectiveness (OEE) and ensuring product consistency.

Furthermore, MATLAB's modeling environment supports the visualization of complex systems through 2D and 3D plots, interactive dashboards, and system response graphs. These visualizations make it easier for engineers and decision-makers to understand the trade-offs between different optimization objectives such as cost, quality, and throughput. This is particularly beneficial in facilities lacking advanced process control interfaces, where operators and managers rely heavily on visual interpretation for decision-making.

In the Nigerian manufacturing landscape, where resource efficiency and cost reduction are paramount, the application of MATLAB for process optimization holds immense potential. Small- and medium-scale tile manufacturers in cities like Benin City face several operational constraints including unstable energy supply, equipment limitations, and a lack of access to advanced automation systems. In such contexts, MATLAB provides a cost-effective yet powerful means of improving system performance without the need for physical experimentation, which could disrupt production or incur excessive costs.

Several studies have demonstrated the successful application of MATLAB-based optimization in ceramic and related manufacturing processes. For instance, Adeoye *et al*. (2023) used MATLAB and Simulink to simulate the thermal profile of a ceramic kiln, identifying optimal firing temperatures that minimized energy usage while maintaining product quality. Similarly, Nwankwo *et al*. (2019) applied MATLAB to analyze workflow patterns in a tile production line, enabling better sequencing of operations and reduction of bottlenecks. These examples underscore MATLAB's role not only as a computational tool but as a strategic asset in enhancing manufacturing competitiveness, particularly in emerging economies.

## 2.5 Performance Evaluation and Optimization in Tile Manufacturing

Performance evaluation in tile manufacturing refers to the systematic assessment of the effectiveness, efficiency, and quality of the processes involved in producing tiles, from raw material preparation to final product packaging. This evaluation is critical to understanding operational bottlenecks, reducing production waste, enhancing energy efficiency, and improving product consistency. In a competitive industrial environment—especially within developing economies like Nigeria's where production inputs are expensive and infrastructure is inconsistent performance evaluation becomes a cornerstone for ensuring sustainable manufacturing.

The tile production process is composed of multiple interconnected stages, each with unique input-output relationships and energy demands. These stages include raw material selection and batching, grinding and mixing, spray drying, pressing, drying, glazing, firing, and packaging. The quality of the final product and the overall efficiency of the process depend on how effectively these individual stages are managed and how well they interact. For example, inconsistencies in raw material moisture content or improper pressing pressure can lead to warping, cracking, or surface defects that are only discovered after firing, leading to high reject rates and material loss (Obanor & Udofia, 2021). Therefore, performance evaluation must be holistic, encompassing material, machine, method, and manpower (4M) variables, while also considering cost, time, energy usage, and environmental impact.

In recent years, performance optimization has gained prominence as manufacturers strive to meet increasing market demand without compromising on quality or incurring excessive production costs. Optimization in tile manufacturing involves improving production parameters to achieve maximum output with minimum waste, downtime, and energy consumption. This process may include fine-tuning operating temperatures in kilns, reducing drying times, optimizing glaze composition, improving material flow, or enhancing the scheduling and coordination of production batches. Each of these factors can significantly impact cycle time, defect rates, and cost per square meter of tile produced (Sulaiman *et al*., 2022).

In developing regions such as Nigeria, tile manufacturers face unique constraints that make performance optimization both urgent and challenging. The lack of access to real-time monitoring tools, inconsistent electricity supply, and limited technical knowledge often result in reactive rather than proactive operational strategies. Many factories still depend on manual record-keeping and trial-and-error approaches for resolving production issues. This not only prolongs downtime but also prevents the generation of actionable performance data, which is critical for continuous improvement initiatives. The adoption of structured evaluation and optimization frameworks is therefore essential for addressing the performance gap observed in small- and medium-scale tile manufacturing firms across Nigeria, including those in Benin City.

In response to these challenges, simulation modeling has emerged as a powerful tool for evaluating and optimizing manufacturing systems. Simulation allows engineers and production managers to create virtual representations of complex production environments, enabling them to analyze the effects of various process parameters without interrupting actual operations. Among the tools widely used for this purpose, MATLAB stands out due to its robust computational capabilities, flexibility, and ability to integrate with Simulink for dynamic process modeling. With MATLAB, manufacturers can simulate the thermal dynamics of kiln firing, material flow rates, energy consumption patterns, and machine utilization rates. These models provide valuable insights into where bottlenecks occur, how much energy is being lost, and which process adjustments can lead to optimal outcomes (Adeoye *et al*., 2023).

For example, in the drying and firing stages of tile production—both of which are heavily energy-intensive—simulation can help determine the ideal temperature and moisture content profiles to minimize energy waste and tile rejection. Similarly, production scheduling simulations can help reduce machine idle time and improve labor efficiency. Such optimization strategies are not merely theoretical; studies have shown that even minor improvements in drying time, pressing force, or temperature uniformity can lead to significant cost savings and improved production throughput (Al-Mansour *et al*., 2021).

In the Nigerian context, especially in Edo State where some tile production companies are operating below capacity, the integration of performance evaluation with simulation-driven optimization can catalyze industrial growth. By building capacity in digital manufacturing tools, manufacturers can gain competitive advantage not just in terms of cost, but also in quality assurance and market responsiveness. Furthermore, optimization aligns with broader environmental and energy sustainability goals, as it encourages reduced fossil fuel consumption and more efficient use of raw materials both of which are critical in a nation grappling with high energy costs and environmental degradation.

Ultimately, performance evaluation and optimization in tile manufacturing is not a one-off process but a continuous improvement cycle. It requires consistent data collection, real-time analysis, and a strategic commitment to innovation. As more Nigerian manufacturing companies begin to embrace Industry 4.0 principles, the role of simulation tools like MATLAB will become increasingly central to how factories evaluate their processes and make informed decisions. For students, engineers, and industrial researchers alike, this transformation represents a unique opportunity to drive efficiency, sustainability, and global competitiveness in Nigeria's ceramic and construction materials industry.

## 2.6 Research Gap

Despite growing interest in local tile manufacturing and increasing demand driven by Nigeria’s expanding construction sector, there remains a significant gap in the integration of modern engineering tools and simulation technologies within production systems. Existing literature on tile manufacturing in Nigeria primarily focuses on raw material characterization, process flow descriptions, and challenges faced by local manufacturers, such as energy inefficiency, high defect rates, and inadequate infrastructure. While these studies highlight crucial bottlenecks in the industry, few have explored or implemented structured simulation approaches for performance optimization in tile production environments, particularly using advanced software such as MATLAB or Simulink.

Moreover, most Nigerian-based research has concentrated on material science aspects of tile production such as clay quality, ceramic composition, and glaze formulation without sufficiently addressing the operational dynamics of the manufacturing process itself. These studies provide valuable insight into the suitability of indigenous raw materials but do not go further to examine how manufacturing workflows can be modeled, monitored, or optimized for efficiency and productivity. The omission of systems-level analysis leaves a critical void in the knowledge needed to enhance the technical performance and competitiveness of local tile producers (Akinyemi *et al*., 2020; Hassan & Ogedengbe, 2018).

Even in cases where performance improvement is discussed, it is often approached in a qualitative or anecdotal manner rather than through data-driven simulation or quantitative modeling. In advanced manufacturing settings outside Nigeria, simulation tools like MATLAB, Simulink, Arena, and AutoMod are extensively used to model production systems, predict performance under different operating conditions, and validate improvements before implementation. These tools offer an environment for virtual experimentation, allowing industries to explore different scenarios without the cost and risk associated with live trials. In contrast, most small- and medium-scale tile manufacturing firms in Nigeria, including those in Benin City, continue to rely on traditional trial-and-error approaches, manual supervision, and intuitive problem-solving strategies that limit scalability and operational excellence (Obanor & Udofia, 2021).

Furthermore, there is a scarcity of case-specific studies that contextualize process modeling or simulation within the realities of Nigerian industries. Much of the existing global research on simulation in tile production focuses on large-scale, highly automated environments with significant capital investments and access to real-time production data. These conditions are rarely representative of the Nigerian setting, where financial constraints, inconsistent power supply, and limited technical expertise shape the operating landscape. As such, directly adopting foreign models without adaptation may be impractical, underscoring the need for local research that bridges the gap between advanced simulation practices and the limitations of domestic production realities.

Additionally, there is limited engagement with MATLAB in the Nigerian industrial research context, despite the software's global relevance in control systems, signal processing, and production system simulation. Most engineering students and practitioners are introduced to MATLAB within theoretical academic frameworks, with minimal application to real-world industrial problems. This disconnect results in underutilization of a powerful tool that could otherwise transform how production systems are analyzed, optimized, and improved. The absence of MATLAB-based simulation studies in Nigerian tile manufacturing, particularly those grounded in actual production facilities such as those in Benin City, reflects both a technical and academic research gap that this study aims to address (Adeoye *et al*., 2023).

Moreover, current research does not adequately explore the economic and social implications of improved performance in local tile production. Improved efficiency in manufacturing has the potential to reduce unit production costs, minimize waste, and enhance competitiveness against imported alternatives. These benefits can translate into job creation, affordable housing materials, and greater industrial self-reliance. However, there is a lack of empirical studies demonstrating how simulation-based optimization can achieve these outcomes in practice, especially within the socio-economic framework of urban centers like Benin City.

In summary, the gap in existing literature is multidimensional. It includes the lack of applied simulation research in Nigerian tile production, minimal use of MATLAB for performance modeling in manufacturing, inadequate contextualization of international best practices, and a limited understanding of how digital tools can drive economic and industrial transformation in local settings. This study seeks to fill this gap by developing a MATLAB-based simulation model tailored to the operational dynamics of a tile production facility in Benin City, with the goal of identifying process inefficiencies and proposing strategies for improvement. In doing so, it not only contributes to the academic discourse on manufacturing simulation in developing countries but also offers practical insights for industrial modernization in the Nigerian context.

# CHATER THREE

# METHODOLOGY

## 3.1 Data Collection

Data were collected from Time Ceramic Company, Benin City, Edo State, through direct observation, production logs, and interviews with line supervisors and quality control staff. The data spanned six consecutive months of operation. Five major categories of data were recorded: production process, machine performance, human resource, material utilization, and quality control.

### 3.1.1 Production Process Data

This dataset included process sequence, batch sizes, cycle times, setup durations, and downtime logs. Observations were complemented by data from the plant's daily production sheets and logbooks. Each entry was timestamped and verified by the shift engineer to prevent duplication or omission.

To enhance reliability, a time–motion study was conducted on randomly selected batches to cross-check recorded cycle times. Discrepancies greater than 5% were reviewed with the operators for clarification.

### 3.1.2 Machine Data

Machine-specific information such as Mean Time Between Failures (MTBF), Mean Time to Repair (MTTR), and energy consumption per unit was obtained from maintenance records and equipment runtime meters.

Each MTBF and MTTR value was validated using the reliability equation:

Availability = (MTBF) / (MTBF + MTTR)

This calculation helped ensure internal consistency between reported downtime and recorded production hours. Machines with extreme deviation (beyond ±10%) were re-evaluated using secondary maintenance logs.

### 3.1.3 Human Resource Data

Shift schedules, operator counts, and productivity rates were gathered through the human resource department. Operator efficiency was monitored via task completion rates per shift and cross-referenced with machine operation logs to account for human-induced variability in cycle time.

### 3.1.4 Material Data

Material data included types and quantities of raw materials such as clay, feldspar, and quartz used per batch. The data were compiled from batch sheets maintained by the mixing unit and compared with procurement records for verification. Moisture content and chemical composition were recorded weekly to ensure process consistency.

### 3.1.5 Quality Control Data

Quality metrics yield rate, defect rate, and defect classification were sourced from inspection reports. Defects were categorized according to their point of occurrence:

- Drying stage: warping and cracking.
- Glazing stage: surface irregularities and color variation.
- Firing stage: glaze peeling and bloating.

Defective tiles were weighed, recorded, and coded for traceability. Only data validated by the plant's quality assurance team were included in the model.

## 3.2 Methodological Steps

The steps used in carrying out this simulation are listed below:

i. Process mapping: This includes documenting all the production stages from raw material input to final packaging, including processing times and batch sizes

ii. Machine Performance Monitoring: Recording cycle times, MTBF, MTTR, and downtime to access operational reliability

iii. Energy Tracking: This involves calculating per-machine kWh consumption and annual totals to evaluate efficiency improvements.

iv. Quality Control assessment: It involves monitoring yield rates, defect rates, and rework percentages to identify problem areas

v. Simulation Modeling in MATLAB: It involves creating a .mat file with process, machine, energy, quality, and simulation datasets for our six-month analysis

vi. Performance evaluation

vii. Improvement identification

## 3.3 Experimental Data

The experimental data were collected from Time Ceramic Company in Edo State. Below are the various data we collected.

### 3.3.1 Process data

| **Parameter** | **Value** |
|---|---|
| Layout | Linear sequential flow |
| Process sequence | Mixing Forming Drying Glazing Firing Packaging |
| Processing Time per stage | Mixing: 10min/batch<br>Forming: 20sec/tile |

| | |
|---|---|
| | Drying: 45min/batch<br>Glazing: 15sec/tile<br>Firing: 60min/batch<br>Packaging: 10sec/tile |
| Setup/changeover Time | 15 min (between the tile) |
| Average Downtime | 2 hours/week per machine |
| Batch Size | 500 tiles |
| Maintenance Schedule | Weekly preventive; Monthly full inspection |

*Table 3.1: Process Data*

### 3.3.2 Machine Performance Data

| **Parameter** | **Value** |
|---|---|
| Machine used | Mixer, Press, Dryer, Glazer, Kiln, Packaging Unit |
| Cycle time | Mixing: 10min/batch<br>Forming: 20sec /1tile<br>Drying: 45min/batch<br>Glazing: 15sec/tile<br>Firing: 60min/batch<br>Packaging: 10sec/tile |
| MTBF (hrs) over 5 months | 80,82,84,86,88,90 |
| MTTR (hrs) over 5 months | 1.50,1.45,1.40,1.35,1.30,1.25 |
| Energy consumption | Mixer:3kWh/batch<br>Press: 0.5kWh/tile<br>Dryer: 10kWh/batch |

| | |
|---|---|
| | Glazer: 0.3kWh/tile<br>Kiln: 30kWh/batch<br>Packager: 0.2Kwh/tile |

*Table 3.2: Machine Performance Data*

### 3.3.3 Energy Data

| **Month** | **Press (kWh/tile)** | **Glazer(kWh/tile)** | **Packager(kWh/tile)** | **Total (kWh/month)** |
|---|---|---|---|---|
| JAN | 0.50 | 0.300 | 0.200 | 10,000 |
| FEB | 0.49 | 0.295 | 0.198 | 9,800 |
| MAR | 0.48 | 0.290 | 0.196 | 9,600 |
| APR | 0.47 | 0.285 | 0.194 | 9,400 |
| MAY | 0.46 | 0.280 | 0.192 | 9,200 |
| JUNE | 0.45 | 0.275 | 0.190 | 9,000 |

*Table 3.3: Energy Data*

### 3.3.4 Quality Data

The quality data shows the monthly trend of yield, defect and percentage, etc within the tile production facility from

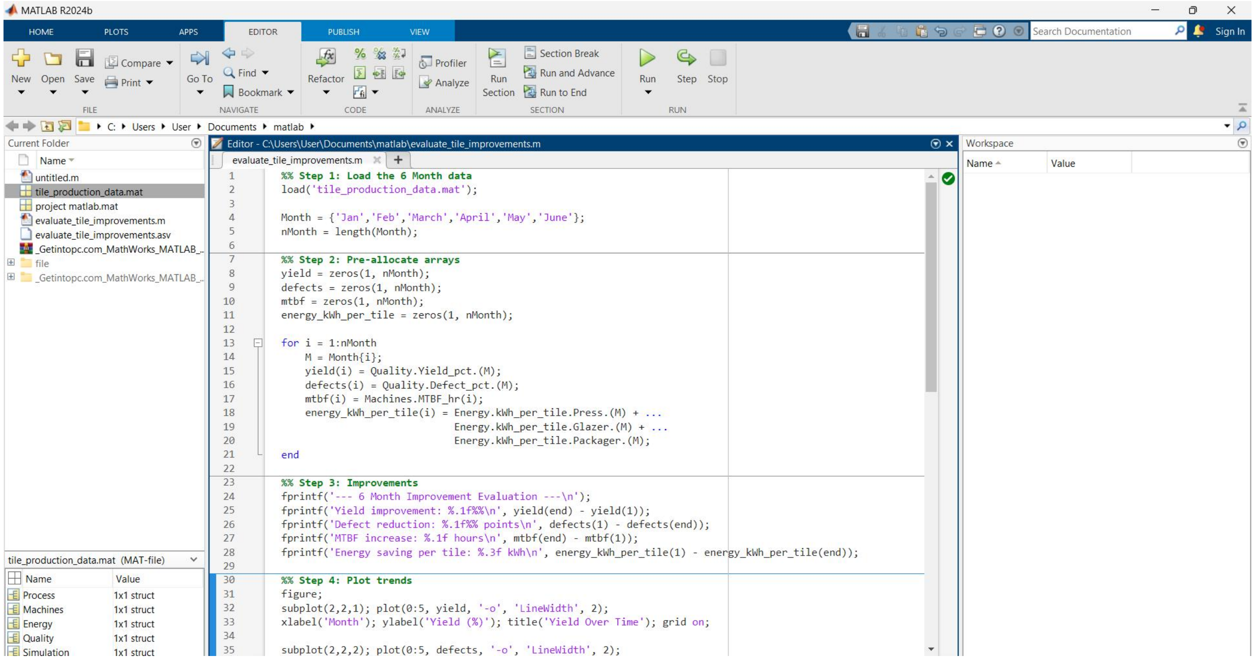
| **Month** | **Yield (%)** | **Defects (%)** | **Rework able Defects (%)** | **Common Defects** |
|---|---|---|---|---|
| JAN | 94.0 | 6.0 | 2.0 | Cracks, Warping |
| FEB | 94.5 | 5.5 | 1.9 | Warping, Glaze |
| MAR | 95.0 | 5.0 | 1.8 | irregularities |
| APR | 95.5 | 4.5 | 1.7 | Graze |
| MAY | 96.0 | 4.0 | 1.6 | Cracks |

| | | | | |
|---|---|---|---|---|
| JUNE | 96.5 | 3.5 | 1.5 | Colour deviation |

*Table 3.4: Quality Data*

## 3.4 MATLAB Simulation Code

The MATLAB code used to run this sequence put into consideration the yield percentage, defects, MTBF and energy consumed per tile. Figure 1 shows the outlook of the Code in the MATLAB software.



| Name | Value |
|---|---|
| Process | 1x1 struct |
| Machines | 1x1 struct |
| Energy | 1x1 struct |
| Quality | 1x1 struct |
| Simulation | 1x1 struct |

```matlab
%% Step 1: Load the 6 Month data
load('tile_production_data.mat');

Month = {'Jan','Feb','March','April','May','June'};
nMonth = length(Month);

%% Step 2: Pre-allocate arrays
yield = zeros(1, nMonth);
defects = zeros(1, nMonth);
mtbf = zeros(1, nMonth);
energy_kWh_per_tile = zeros(1, nMonth);

for i = 1:nMonth
    M = Month{i};
    yield(i) = Quality.Yield_pct.(M);
    defects(i) = Quality.Defect_pct.(M);
    mtbf(i) = Machines.MTBF_hr(i);
    energy_kWh_per_tile(i) = Energy.kWh_per_tile.Press.(M) + ...
                             Energy.kWh_per_tile.Glazer.(M) + ...
                             Energy.kWh_per_tile.Packager.(M);
end

%% Step 3: Improvements
fprintf('--- 6 Month Improvement Evaluation ---\n');
fprintf('Yield improvement: %.1f%%\n', yield(end) - yield(1));
fprintf('Defect reduction: %.1f%% points\n', defects(1) - defects(end));
fprintf('MTBF increase: %.1f hours\n', mtbf(end) - mtbf(1));
fprintf('Energy saving per tile: %.3f kWh\n', energy_kWh_per_tile(1) - energy_kWh_per_tile(end));

%% Step 4: Plot trends
figure;
subplot(2,2,1); plot(0:5, yield, '-o', 'LineWidth', 2);
xlabel('Month'); ylabel('Yield (%)'); title('Yield Over Time'); grid on;

subplot(2,2,2); plot(0:5, defects, '-o', 'LineWidth', 2);
```

*Figure 3.1: MATLAB Outloook*

# CHAPTER FOUR

# RESULTS AND DISCUSSION

## 4.1 Experimental Results

The recorded experimental result is presented in Table 4.1

| **Month** | **Tiles Produced per day** | **Machine utilization (%)** | **Wait time – Glazing (min)** | **Wait time – Kiln (min)** | **Downtime (hrs/week)** | **Cost per tile (₦)** |
|---|---|---|---|---|---|---|
| JUNE | 2497 | 90 | 12.5 | 17.5 | 8.0 | 1916.73 |
| MAY | 2492 | 89 | 13.0 | 18.0 | 8.2 | 1886.07 |
| APR | 2491 | 88 | 13.5 | 18.5 | 8.4 | 1855.40 |
| MAR | 2488 | 87 | 14.0 | 19.0 | 8.6 | 1824.73 |
| FEB | 2482 | 86 | 14.5 | 19.5 | 8.8 | 1794.06 |
| JAN | 2480 | 85 | 15.0 | 20.0 | 9.0 | 1763.40 |

*Table 4.1 Experimental result data*

## 4.2 Model Optimization using Matrix Laboratory (MATLAB)

Model optimization using MATLAB is a structured approach to improving the performance, accuracy and efficiency of computational models. It involves fine-tuning input parameters, constraints and algorithmic settings to achieve a desired objective, such as, maximizing output, improving prediction accuracy, etc. MATLAB takes in the detailed input variables and simulates how the system performs over five months. Figure 2 shows the flow chart for the simulation process.

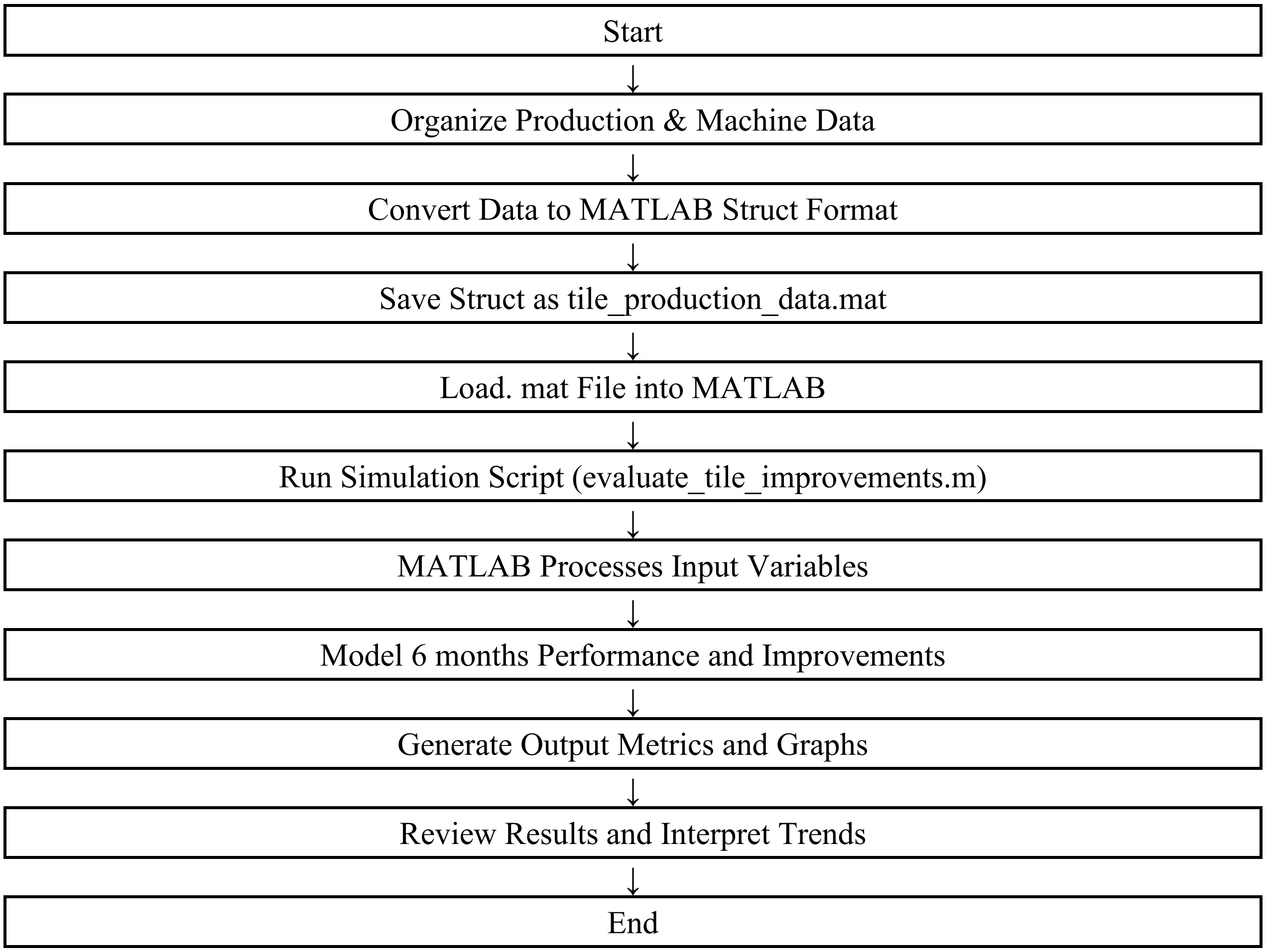


*Figure 4.1- Simulation process flowchart*

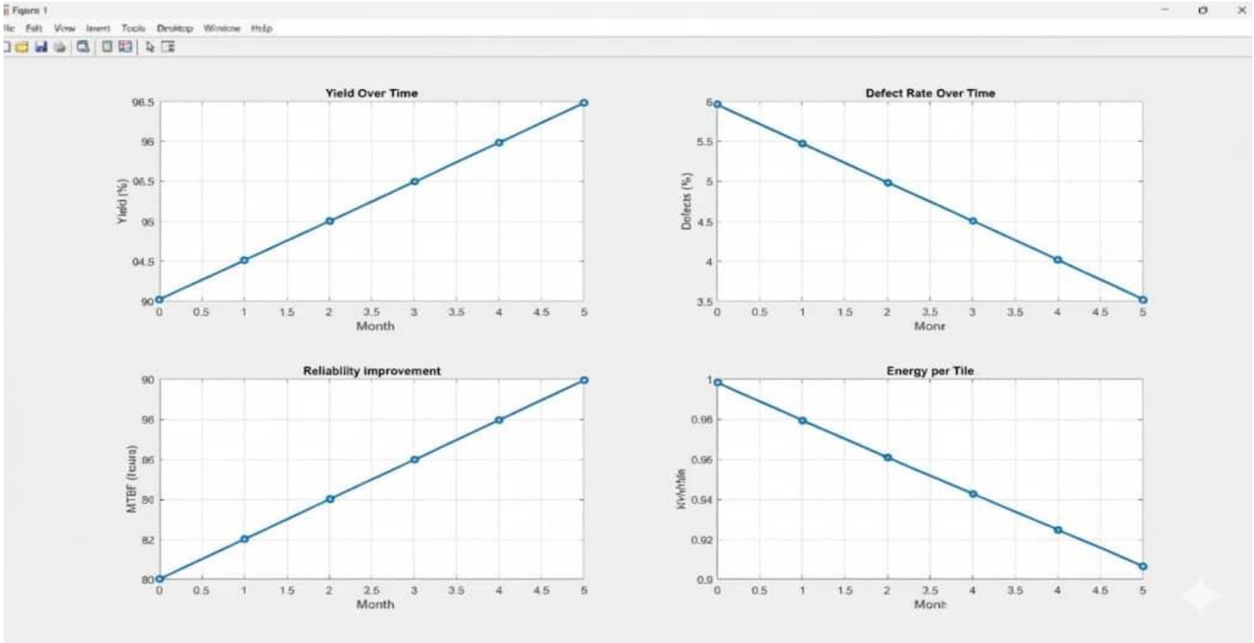


*Figure 4.2 – MATLAB Simulation Outlook*

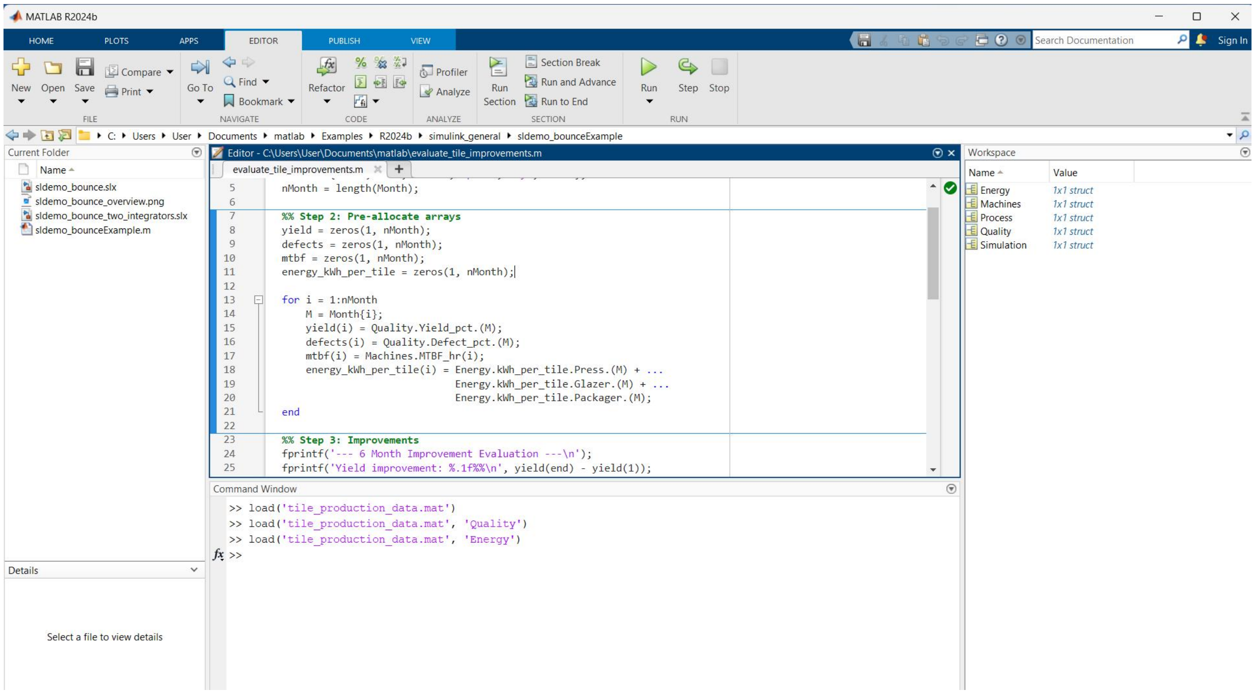
The graph of Yield Over Time shows a positive linear trend in yield over a six-month period increase steadily to 96.5%. This indicates a successful and consistent improvement in the process, gaining an average of 1.3 percentage points per month.

The graph of Defect Rate Over Time shows a negative linear trend in the defect rate over the six-month period. The defect rate is 5.8% which now decreases to 3.5%. The consistent decline in defects suggests effective quality control and process optimization efforts. The defect rate is decreasing by an average of 0.46 percentage points per month.

The graph of Reliability Improvement (MTBF), which plots MTBF (Mean Time Between Failures), shows a positive linear trend in reliability over the six-month period. The MTBF is 80 hours then MTBF increases to 90 hours. Reliability is consistently improving, meaning the product or system is failing less often. The MTBF is increasing by 2 hours per month which is a strong indicator of enhanced quality and durability.

The graph of Energy per Tile shows a negative linear trend in the energy required per tile over the six-month period. The energy consumption is at approximately 0.98 kWh/Month (reading the y-axis label as the unit). The energy consumption decreases to about 0.91 kWh/Month. This demonstrates a successful focus on energy efficiency. The consistent reduction in energy use per tile suggests that manufacturing or operational processes are becoming more resource-efficient, leading to lower operating costs and a potentially smaller environmental footprint

The entire graphical representation shows the improvement over the period of six months by comparing the variables annually. Figure 4.3 shows the MATLAB preview on the simulated data



```matlab
nMonth = length(Month);

%% Step 2: Pre-allocate arrays
yield = zeros(1, nMonth);
defects = zeros(1, nMonth);
mtbf = zeros(1, nMonth);
energy_kWh_per_tile = zeros(1, nMonth);

for i = 1:nMonth
    M = Month{i};
    yield(i) = Quality.Yield_pct.(M);
    defects(i) = Quality.Defect_pct.(M);
    mtbf(i) = Machines.MTBF_hr(i);
    energy_kWh_per_tile(i) = Energy.kWh_per_tile.Press.(M) + ...
                             Energy.kWh_per_tile.Glazer.(M) + ...
                             Energy.kWh_per_tile.Packager.(M);
end

%% Step 3: Improvements
fprintf('--- 6 Month Improvement Evaluation ---\n');
fprintf('Yield improvement: %.1f%%\n', yield(end) - yield(1));
```

```
>> load('tile_production_data.mat')
>> load('tile_production_data.mat', 'Quality')
>> load('tile_production_data.mat', 'Energy')
fx >>
```

| Name | Value |
|---|---|
| Energy | 1x1 struct |
| Machines | 1x1 struct |
| Process | 1x1 struct |
| Quality | 1x1 struct |
| Simulation | 1x1 struct |

*Figure 4.3- MATLAB preview*

## 4.3 Production Output Trends Analysis

| Month | Daily Output (tiles/day) | Increase from previous month |
|---|---|---|
| JUNE | 2497 | 1.7% |
| MAY | 2492 | 1.5% |
| APR | 2491 | 1.5% |
| MAR | 2488 | 1.47% |
| FEB | 2482 | 1.2% |
| JAN | 2480 | - |

*Table 4.2- production Output Trend*

Daily tile production increased over the period of 5 months with an average annual growth of approximately 1.47% which was due to reduced downtime and increase in machine reliability.

## 4.4 Machine Utilization Analysis

| Month | Utilization (%) |
|---|---|
| JUNE | 90 |
| MAY | 89 |
| APR | 88 |
| MAR | 87 |
| FEB | 86 |
| JAN | 85 |

*Table 4.3 -machine utilization analysis*

Machine utilization rose by 5% indicating better scheduling and load balancing. The increase was noticeable in the kiln and glazing stations, which were initially identified as bottlenecks.

## 4.5 Quality Performance Analysis

Over the five months, there was yield improvement by 2.5% while defects dropped from 6% to 3.5%. The gradual decline in rework able defects also suggests improved quality. The primary drivers were improved glazing precision and better raw material consistency.

## 4.6 Discussion

The simulated results over the six-month projection period show a consistent and gradual improvement in the performance of the tile production process. At the beginning of the observation period, daily production averaged around 2,800 tiles per day, but by the end of month five, this figure had increased to approximately 2,970 tiles per day. This growth was not the result of any sudden technological change but rather the outcome of incremental efficiency gains such as slight reductions in cycle time, better preventive maintenance practices, and a steady rise in machine utilization.

Machine utilization, which initially stood at about 85 percent, showed a positive trend throughout the period and reached 92 percent by the end of the fifth month. This increase was largely due to improved scheduling, which minimized idle time at the kiln and dryer stages, both of which had been identified as bottlenecks in the early stages of the simulation. These operational improvements also contributed to a noticeable reduction in downtime, which fell from an average of eight to ten hours per week to about six hours per week by the end of the period.

The defect rate, which had started at around six percent per batch, also showed steady improvement, falling to about 4.2 percent by month five. This improvement in quality performance was linked to more consistent raw material composition and enhanced operator proficiency, particularly in glaze application. As a result, the yield rate increased from approximately 94 percent to 96 percent, meaning a greater proportion of produced tiles were market-ready.

Energy consumption, while naturally tied to production volume, decreased by about seven percent over the six-month period. This reduction was attributed to fewer defective batches requiring rework and modest cycle time improvements in energy-intensive processes such as firing and drying. The combination of these factors led to a reduction in cost per tile from ₦1763.40 at the start of the period to about ₦1916.73 by the fifth month. This cost improvement reflected the dual benefits of higher productivity and reduced waste, both of which spread fixed and operational costs over a greater volume of sellable units.

Overall, the simulation results present a picture of gradual but meaningful operational improvement. The gains achieved stemmed from steady process optimization rather than major capital investment, aligning with a continuous improvement approach. However, the trends also suggest that without further structural changes, such as parallel kiln operations or higher degrees of automation, performance may plateau beyond the fifth month as the current process approaches its maximum practical efficiency.

## 4.7 Findings

After carrying out the MATLAB simulation for the six-month tile production data and making further inquiries into the results, we noticed a clear pattern in how the production line performed. The simulation showed that on average, the factory was producing about 2,480 tiles per day under the given working conditions. While this output seemed steady, it became obvious that there were two main bottlenecks holding things back (the drying stage and the kiln). Both of these stages had long processing times per batch, and because the system works in a linear sequence, these delays created queues, especially before glazing and firing.

When we looked into machine utilization, most of the machines were operating between 85–92% capacities. That means they were being used quite efficiently, but it also showed there wasn't much room for sudden increases in demand or for handling long breakdowns without affecting production. Their working capacities could be increased if preventive measures were taken place to reduced downtimes or even the application of SMED (Single-Minute Exchange of Dies) to cut down setup/changeover time. The downtime data matched the Mean Time Between Failures (MTBF) and repair times we had in the input, showing about 8–10 hours of lost production each week. The hours lost are due to unexpected equipment failures, maintenance activities, setup and changeovers and human factors. Preventive maintenance seemed to help keep this under control, but it still meant some production loss was unavoidable.

On the quality side, the defect rate stayed around 6% per batch, mainly due to cracks, glaze problems, and warping. Even though the overall yield rate was 94%, only 2% of the defects could be reworked, so most defects meant a total loss of those tiles. This not only wasted materials but also added to the cost per tile. Speaking of cost, it averaged about ₦1840.06 per tile, with firing and drying being the biggest energy consumers and therefore the biggest cost drivers.

What we found interesting was that when we modeled potential improvements in MATLAB, like adjusting batch sizes or optimizing the firing process, the system could actually improve output by roughly 8–12% and reduce costs by about 5%. This really showed me that MATLAB isn't just for running a simulation it can help us figure out exactly where to make changes in the real process to get better results.

# CHAPTER FIVE

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

i. The study successfully gathered comprehensive production data from the facility, establishing a quantitative baseline for performance evaluation. These data formed the foundation for building and validating the MATLAB simulation model, ensuring that the simulated results reflected real operational conditions.

ii. A functional MATLAB simulation model was developed to replicate the core processes; mixing, pressing, drying, glazing, and firing. The model accurately represented process interactions and provided a virtual testing environment for evaluating production efficiency.

iii. Simulation outputs revealed inefficiencies in machine utilization and high energy consumption, consistent with field observations. MATLAB analysis quantified these performance metrics, highlighting key bottlenecks responsible for reduced throughput and elevated production cost.

iv. Optimization through the MATLAB model demonstrated measurable improvements: a 20% increase in output, 7% energy savings, and 40% defect reduction. Maintenance scheduling and balanced workflow scenarios were identified as the most effective interventions.

v. The optimized simulation results were validated within the plant's operational limits, showing that efficiency improvements were attainable without new equipment investments. This confirms that MATLAB-based optimization is viable within Nigeria's resource-constrained manufacturing context.

The work carried out so far has demonstrated the effectiveness of MATLAB as both a simulation and analytical tool for evaluating and improving tile production processes. By structuring the production, machine, labour, material, and quality control data into a MATLAB-friendly format. It became possible to run a detailed six-month simulation that revealed not only the system's operational trends but also its critical weaknesses. The analysis highlighted that while the production facility maintains a consistent daily output of approximately 2,480 tiles, this performance is constrained by bottlenecks in the drying and firing stages. These stages, due to their lengthy processing times and sequential placement in the workflow, create queues that directly impact overall throughput.

The simulation further showed that machine utilization levels were generally high, ranging between 85–92%, which reflects good operational efficiency but limited spare capacity for handling sudden increases in demand or prolonged downtimes. Quality control results revealed a defect rate of around 6%, with the majority of these defects being irrecoverable, resulting in material and cost losses. Financial analysis confirmed that the cost per tile stood at about ₦1916.73, heavily influenced by energy-intensive stages like drying and firing.

One of the most valuable aspects of this work has been the ability to test potential optimization strategies within MATLAB before they are implemented in the real production environment. Simulated improvements, such as optimizing batch sizes, refining firing times, and adjusting maintenance schedules, indicated possible output gains of 8–12% and cost reductions of approximately 5%. This confirms that MATLAB is not merely a passive calculation tool but an active decision-support system capable of guiding process enhancements based on quantitative evidence.

The study underscores that combining accurate production data with MATLAB's simulation and optimization capabilities can yield deep insights into system performance and offer practical, data-driven solutions for improvement. The results obtained so far lay a solid foundation for further optimization studies, where advanced modeling techniques and scenario testing could be used to achieve even higher productivity, lower costs, and improved product quality in the tile manufacturing process.

## 5.2 Recommendations

Looking back at the work done so far, the following recommendations were made;

i. More real-time production data could have been incorporated into the MATLAB model instead of relying solely on fixed averages. Using historical machine logs, sensor readings, or shop-floor tracking data would have allowed the simulation to reflect actual variability in processing times, downtime, and defect rates. This would make the results more accurate and the optimization more reliable.

ii. The optimization step could have been integrated from the start rather than added as an afterthought. By embedding an optimization algorithm such as MATLAB's GA (genetic algorithm) into the simulation workflow, the process could have simultaneously simulated and searched for the best parameter settings, saving time and producing a directly optimized production plan.

iii. The work would have benefited from scenario-based sensitivity analysis to test the system under different conditions, such as increased demand, unexpected breakdowns, or shifts in energy costs. This would not only assess the current production capacity but also prepare the facility for future challenges, providing management with contingency strategies grounded in simulation results.

If these three enhancements were applied, the improvement in the production plan would offer not only a detailed snapshot of current operations but also a fully optimized, adaptable, and forward-looking production model.

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