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# Evaluating Industrial Robots as A Strategy for Manufacturing Cost Optimization in Lafarge Cement Company, Calabar

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## Abstract

*The study evaluated the use of industrial robots as a strategy for manufacturing cost optimization at Lafarge Cement, Calabar, driven by the growing global demand for efficient, cost-effective, and technologically advanced manufacturing systems. The research focused on robotic adoption, its impact on production efficiency and product quality, cost reduction, and implementation challenges. Using a descriptive survey design, data were collected from a population of 1,124 technical and operations personnel, with a sample size of 287 determined via Taro Yamane's formula and selected through proportionate stratified and purposive sampling across four departments. Primary data were gathered through structured questionnaires and semi-structured interviews, while secondary data were obtained from maintenance and production records spanning 2021–2025, sourced from maintenance logs and financial reports tracking key performance indicators such as equipment availability, mean time between failures, production efficiency, energy consumption, and product quality. Descriptive statistics (mean and standard deviation) and one-sample t-tests at a 0.05 significance level were used to analyze survey data, while secondary data were analyzed through trend analysis and comparative evaluation to assess pre- and post-robotics performance. These combined methods enabled a comprehensive evaluation of both survey responses and operational data. Findings indicated moderate robotic adoption (mean = 3.23), significant improvements in production efficiency and product quality (mean = 3.98), and meaningful cost reduction (mean = 3.90), with notable implementation challenges (mean = 3.90). Three of four null hypotheses were rejected, confirming robotics' significant influence on efficiency, quality, and cost, while the hypothesis on adoption level was not rejected. The study concludes that industrial robotics have strong potential to optimize cement manufacturing operations but require overcoming structural and technical barriers, offering valuable insights for practitioners, policymakers, and researchers aiming to modernize manufacturing in emerging economies.*

**Keywords:** *Industrial Robots, Cost Optimization, Production efficiency, Production quality, Cost reduction, Lafarge Cement*

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**Introdution**

As the manufacturing sector continues to evolve and wax stronger, the integration of industrial robotics has become a pivotal strategy for achieving enhanced productivity, operational efficiency, and cost optimization. Automation technologies have tremendously improved in recent years, giving rise to transformation driven by the pursuit of competitiveness and sustainability in increasingly volatile markets. Adebayo *et al*. (2024) observed thatrobotics, particularly in industrial contexts, has moved beyond experimental or high-tech niches to become a core component of modern manufacturing systems. Pradeep *et al*. (2024) buttressed this claim, pointing out that industrial robotics are reshaping how products are designed, produced, and delivered.

The cement manufacturing sector, traditionally reliant on labor-intensive and energy-consuming processes, is no exception to this shift. The industry has remained one of the most critical segments of the construction and infrastructure development value chain. Nevertheless, Urrea-Kern (2025) asserted that the cement industry faces persistent pressures to enhance operational efficiency while minimizing production costs and environmental impacts. According to Adebayo *et al*. (2024), robotics and automation offer promising avenues for addressing these challenges.

Globally, leading cement manufacturers have increasingly adopted industrial robots for tasks such as materials handling, kiln monitoring, packaging, and quality control. These technologies are not only instrumental in improving the consistency and quality of cement products but also play a role in reducing workplace hazards and labor costs. The integration of robotics has been particularly valuable in addressing labor shortages, ensuring production continuity during disruptions such as pandemics, and complying with stricter occupational health and safety regulations (Țîțu*et al*., 2024; Patel, 2025).

In Africa, however, the diffusion of robotic automation technologies into cement manufacturing remains limited and uneven. While multinational companies like Lafarge operate across the continent with access to global technologies, regional facilities often lag in adopting cutting-edge systems due to infrastructural constraints, high capital costs, limited technical expertise, and inconsistent policy support. In the Nigerian context, the cement industry is central to national economic development, contributing significantly to construction, housing, and industrial growth. However, operational inefficiencies, high energy consumption, and cost volatility persist as major challenges (Kermeli*et al*., 2011).

Calabar, home to a significant Lafarge facility, exemplifies this tension between traditional manufacturing models and the need for modernization. As demand for cement surges due to urbanization and infrastructure development in southern Nigeria, production facilities are under increasing pressure to scale operations efficiently while maintaining product quality and controlling costs. The potential role of industrial robots in supporting these goals is becoming increasingly relevant, especially as companies seek competitive advantages through technological innovation (Mikulčić*et al*., 2013; Mielli, 2012).

At the same time, the adoption of robotics in cement manufacturing introduces complex technological and organizational considerations (Urrea-Kern, 2025). Implementation challenges such as high upfront investment pose significant barriers. Moreover, in contexts like Calabar where infrastructural limitations and energy reliability issues are prevalent, deploying robotics requires careful adaptation to local conditions (Adebayo *et al*., 2024). Technological trends in the industrial robotics domain also influence the pace and nature of adoption. Recent advancements have enabled the development of collaborative robots (cobots), capable of working alongside human operators in dynamic environments. These systems offer flexibility, real-time decision-making, and learning capabilities, making them suitable for the semi-structured and batch-oriented operations common in cement production lines (Țîțu*et al*., 2024; Pradeep *et al*., 2024). However, the successful deployment of such systems depends not only on technical readiness but also on organizational culture, policy incentives, and sustained investment.

Despite the global enthusiasm surrounding robotics, certain dimensions remain underexplored, particularly in emerging economies. There is a notable paucity of empirical research focusing on the adoption, performance outcomes, and implementation challenges of industrial robots in African cement manufacturing contexts. Most existing literature focuses on highly industrialized regions, with limited attention to how robotics function within the infrastructural, economic, and human resource constraints typical of facilities like Lafarge Cement in Calabar (Adebayo *et al*., 2024; Urrea-Kern, 2025). This gap underscores the need for localized studies that contextualize global technologies within specific operational realities.

**Statement of the Problem**

The manufacturing sector is increasingly becoming competitive and rising demands for cost-effective, efficient, and technologically adaptive manufacturing processes has never been more urgent. As global supply chains confront disruptions, energy costs rise, and environmental regulations tighten, industries are under pressure to modernize their operations to stay viable. The cement manufacturing sector being a cornerstone of infrastructure development, is particularly affected. It faces unique challenges due to its capital intensity, energy consumption, and need for consistent product quality.

Despite global advancements in automation, including the integration of industrial robots in cement production lines, the extent to which these innovations have been adopted and effectively applied in sub-Saharan Africa remains limited. At Lafarge Cement, Calabar, there is an observable disconnect between global best practices and localized implementation strategies. The core problem lies in the uncertain extent to which industrial robots have been adopted, their impact on production efficiency and cost reduction, and the challenges encountered in their deployment. Without clarity on these factors, efforts to optimize manufacturing performance risk being misguided, fragmented, or ineffective.

Existing research has established the benefits of industrial robotics in enhancing efficiency, improving quality, and lowering operational costs across various manufacturing sectors (Adebayo *et al*., 2024; Urrea-Kern, 2025). However, studies specific to cement production in African contexts, particularly in Nigeria, are scarce. There is a marked absence of empirical evidence on how robotics performs in the unique operational environment of Lafarge Cement, Calabar. This knowledge gap hampers the development of tailored strategies for effective implementation and limits the potential for policy or managerial interventions.

The consequences of this gap are significant. Without a comprehensive understanding of the role of robots in optimizing production, the company risks persisting inefficiencies, inflated costs, and diminished competitiveness. These challenges not only impact the firm's bottom line but also hinder broader industrial growth, job creation, and infrastructural progress in the region. If left unaddressed, the disconnect between technological potential and actual practice could widen, deepening inefficiencies in a critical industry.

**Aim and Objectives of the Study**

The study aims to evaluate industrial robots as a strategy for manufacturing cost optimization in Lafarge cement company, Calabar. The specific objectives of the study are to;

i. Assess the level of adoption and application of industrial robots in the manufacturing processes at Lafarge Cement, Calabar.
ii. Determine the impact of industrial robots on production efficiency and production quality.

**Research Question**

With respect to the research objectives, the following research questions are formulated to steer the study:

i. What is the current level of adoption and application of industrial robots in the manufacturing processes at Lafarge Cement, Calabar?
ii. How have industrial robots affected production efficiency and product quality at Lafarge Cement, Calabar?

**Statement of Hypotheses**

The following hypotheses guide the study;

i. Industrial robots are not significantly adopted and applied in cement manufacturing process at Lafarge Cement.
ii. The deployment of industrial robots does not significantly improve production efficiency and product quality at Lafarge Cement, Calabar.

**Significance of the Study**

The study has significant value for multiple stakeholders within the manufacturing and industrial development landscape. For Lafarge Cement, Calabar, the research provides actionable insights into how industrial robotics can be leveraged to optimize production efficiency, reduce operational costs, and improve product quality. These findings can inform strategic decision-making on technology investments, workforce planning, and process improvements. Industrial engineers and plant managers will benefit from a deeper understanding of robotics' operational impacts, offering a foundation for practical interventions tailored to local conditions. Policymakers and regulatory bodies may also draw from the study to design more supportive frameworks that encourage the adoption of advanced manufacturing technologies in Nigeria's cement sector. For researchers and academics, the study contributes to the limited body of literature on robotics in African industrial contexts, creating a platform for further exploration. Evidently, the study supports national efforts toward industrial modernization by providing data-driven evidence to bridge the gap between automation potential and practical application in emerging economies.

**Scope of the Study**

This study investigates the adoption and application of industrial robots as a strategy for manufacturing cost optimization in the cement industry, with a specific focus on Lafarge Cement Company in Calabar, Nigeria. It examines four key dimensions: the extent of robotic adoption, their impact on production efficiency and product quality, their contribution to cost reduction, and the challenges encountered during implementation. These objectives are designed to align closely with the broader research problem of technological integration and process improvement in industrial manufacturing.

Geographically, the study is confined to the Lafarge Cement facility in Calabar, excluding other branches or cement plants within Nigeria or abroad. This localized focus enables an in-depth examination of robotic deployment in a specific operational context, providing insights grounded in real-time industrial conditions.

**Conceptual Review**

**Industrial Robotics**

Industrial robotics refers to the design, deployment, and operation of programmable mechanical systems commonly known as robots, specifically engineered to perform production-related tasks in manufacturing environments. These tasks include but are not limited to material handling, welding, painting, assembling, packaging, and inspection. Distinguished by their autonomy, precision, and repeatability, industrial robots are pivotal in automating labor-intensive and repetitive processes, thus serving as a core component of modern production systems. In the context of this study, understanding the concept of industrial robotics is essential for evaluating how such technologies may be harnessed to improve manufacturing outcomes. This is particularly with respect to cost reduction, production efficiency, and quality assurance in the cement manufacturing sector. The contemporary understanding of industrial robotics is deeply informed by the accelerating digitization of manufacturing, often conceptualized as "Industry 4.0." Within this framework, robotics is not merely an add-on to existing processes but a transformative enabler of intelligent, data-driven production systems. Karabegović *et al*. (2022) emphasize that robotic systems, both industrial and service-based, are foundational to smart manufacturing initiatives globally. These systems integrate sensors, actuators, and artificial intelligence to perform tasks with high precision and adaptability in dynamic environments. The shift from traditional to collaborative robots (cobots), which can safely work alongside humans, reflects this evolving paradigm and introduces new flexibility in process design and workforce collaboration.

**Application of Industrial Robots in Manufacturing**

The application of industrial robots in manufacturing represents one of the most significant technological transformations in modern industry. Industrial robots, defined as programmable, multifunctional manipulators designed to move materials, tools, or specialized devices through various programmed motions, are increasingly deployed across a wide range of manufacturing sectors (Shinde *et al*., 2024). Their application is particularly relevant in environments that demand high precision, speed, consistency, and productivity; characteristics that traditional labor-intensive processes often struggle to maintain. Understanding how industrial robots are applied in manufacturing is essential to appreciating their potential contribution to production efficiency, product quality, and cost optimization, especially within sectors such as cement manufacturing where operational reliability is critical.

**Product Quality and Robotics**

The application of industrial robots in manufacturing has transformed quality assurance processes by minimizing human error, standardizing operations, and enabling precision-driven interventions. DeStefano *et al*. (2019) demonstrated that robot integration into production systems has a positive association with export quality, especially in high-income economies where within-product quality improvements are more pronounced. Similarly, Li (2024) found that robot adoption significantly upgraded export product quality in Chinese enterprises, primarily through mechanisms such as enhanced trade competitiveness and first-mover advantage. These empirical findings suggest that robotics can contribute to both the functional and perceived quality dimensions of manufactured products by embedding uniformity, accuracy, and feedback control into production routines. Robotic technologies enhance product quality through several pathways. First, robots facilitate consistent process execution across production cycles, thereby reducing variability and ensuring adherence to tight tolerances. Second, their integration with artificial intelligence (AI) and machine learning enables real-time monitoring and automated correction of deviations. Bechoo*et al*. (2023), AI-driven robotic systems can detect faults, analyze root causes, and adapt processes to correct anomalies before they affect product integrity. This capacity for real-time, data-informed quality control represents a major departure from traditional post-production inspection, allowing manufacturers to address defects proactively and enhance overall process reliability.

**Cost Optimization through Automation**

Cost optimization in manufacturing has become an imperative strategy in the face of escalating global competition, fluctuating input costs, and increasing demand for high-quality products delivered efficiently. Within this context, industrial automation particularly the deployment of robotics, has emerged as a transformative tool for minimizing operational expenses, enhancing process consistency, and reducing waste. This sub-section examines the concept of cost optimization through automation, with a focus on its implications in manufacturing environments. Cost optimization through automation is achieved by reducing direct labor requirements, minimizing downtime, improving resource utilization, and enhancing precision and repeatability in production (Amirova, Osadchij, & Stepanova, 2024). In particular, robotic systems are capable of performing repetitive, high-volume, and hazardous tasks with greater efficiency than human workers, thereby streamlining production processes and decreasing the likelihood of costly errors or accidents.

**Industrial Robotics in Emerging Economies**

Robotics adoption in emerging economies is often driven by external market pressures, such as global value chain participation and export competitiveness. DeStefano, Backer, and Suh (2019), emerging economies have begun to integrate robotics in ways that influence production quality and export performance, although the quality gains differ from those seen in high-income contexts. For instance, whereas developed countries tend to experience within-product quality improvements, emerging economies see broader gains across product categories, reflecting their initial technological entry point (DeStefano *et al*., 2019). This suggests that industrial robotics may play a different, yet significant, role in shaping industrial competitiveness in lower-income settings.

However, the path to effective robotics implementation in developing regions is obstructed by several constraints. As Gravina and Pappalardo (2022) report, robotization in advanced economies can produce adverse externalities for emerging economies, particularly in labor-intensive sectors vulnerable to automation-induced displacement. These dynamics may erode employment in sectors that have historically anchored industrial development in emerging nations (Gravina & Pappalardo, 2022). Consequently, while robotics may offer productivity gains, they also pose structural labor challenges that must be carefully managed.

At the policy level, governments in emerging economies have increasingly recognized the importance of robotics for industrial advancement. Some countries have begun introducing strategic plans, fiscal incentives, and public-private partnerships to foster automation uptake. For example, efforts to reduce reliance on foreign technology through domestic robot manufacturing or subsidize the cost of automation reflect attempts to localize the benefits of robotics while managing risks of dependency or exclusion (DeStefano *et al*., 2018). Yet, such efforts are still in nascent stages, and their effectiveness varies widely across national contexts.

Another critical factor shaping the role of industrial robotics in emerging economies is the capacity of firms to absorb new technologies. Firms in these settings often struggle with limited access to capital, inadequate infrastructure, and shortages of skilled labor. As reported in recent studies, the lack of robotics-specific education and training institutions undermines the readiness of many manufacturing environments to accommodate advanced technologies. This has implications not only for immediate adoption but also for the sustainable operation, maintenance, and upgrading of robotic systems (Smith *et al*., 2024). In sum, the discourse on industrial robotics in emerging economies highlights both the promise and the complexity of automation-driven industrial transformation. While robotics may enhance competitiveness and operational excellence, their integration requires nuanced strategies sensitive to each country's economic structure, labor dynamics, and institutional maturity. For countries like Nigeria, the effective harnessing of robotics could support inclusive industrial development—if implemented in a way that aligns with broader developmental goals and capabilities.

**Theoretical Framework**

The Technology Acceptance Model (TAM), by Fred Davis in 1986 guided the study

**Technology Acceptance Model (TAM)**

The Technology Acceptance Model (TAM) was introduced by Fred Davis in 1986 and formally published in 1989 as a theoretical framework for understanding how users come to accept and use a technology. Grounded in the Theory of Reasoned Action (TRA), TAM posits that perceived usefulness (PU) and perceived ease of use (PEOU) are the primary determinants of an individual's intention to use technology (Davis, 1989). Since its inception, TAM has undergone various modifications and extensions and remains a dominant framework in explaining user adoption behaviors across multiple disciplines, including healthcare, finance, education, and industrial systems (Scherer *et al*., 2019). In the context of manufacturing; particularly the integration of industrial robotics, TAM provides valuable insights into organizational readiness, employee acceptance, and the behavioral dynamics shaping technology uptake.

While TAM has shown enduring applicability, recent research has highlighted its evolving relevance in emerging technology domains. Scherer *et al*. (2019), in a meta-analytic review of 114 empirical TAM studies, noted that while PU and PEOU consistently predict adoption, their relative influence can vary based on contextual variables such as industry type, user expertise, and organizational culture. In manufacturing environments, where technological complexity and workplace routines are significant, these contextual moderators become crucial for refining TAM's predictive power. Studies have thus proposed the integration of external variables; such as trust in automation, perceived behavioral control, and organizational support, to better tailor TAM to industrial applications (Nurqamarani*et al*., 2021).

In the context of cement manufacturing, especially in developing economies, TAM offers a lens to understand both management and workforce engagement with industrial robotics. The sector's capital-intensive nature, combined with its traditional reliance on labor and mechanization, makes the shift to robotics a substantial organizational change. Here, PU may manifest through perceived gains in production consistency, operational efficiency, or reduced downtime, while PEOU could relate to the perceived learning curve associated with using robotic systems. If these factors are not adequately addressed, even technologically feasible systems may encounter resistance at the user level (Chukwuere *et al*., 2022).

The TAM also serves as a useful model for examining adoption patterns across different levels of stakeholders; from engineers and machine operators to plant managers and policymakers. For decision-makers in cement manufacturing firms, understanding the predictors of technology acceptance enables better planning of workforce transition, targeted training programs, and structured implementation strategies. As highlighted by Scherer *et al*. (2019), aligning TAM variables with policy and organizational support systems not only facilitates smoother adoption but also mitigates long-term resistance to automation.

Moreover, the growing complexity of industrial technologies necessitates continuous adaptation of TAM. Emerging studies advocate for "TAM3" or extended TAM models that integrate factors such as perceived risk, subjective norms, and even emotional responses to automation (Nurqamarani*et al*., 2021). These additions help tailor TAM to high-risk, high-reward environments such as manufacturing, where trust in technology and institutional stability often govern adoption outcomes.

In summary, the Technology Acceptance Model remains an indispensable theoretical tool in analyzing the adoption of industrial robotics in cement manufacturing. Its dual emphasis on perceived usefulness and ease of use offers a structured way to evaluate the psychological and behavioral dimensions of technology acceptance. As cement companies increasingly turn to robotics for operational optimization, TAM provides a valuable framework to assess stakeholder readiness, anticipate adoption barriers, and design supportive environments conducive to technological change. Within this study, TAM will guide the conceptual understanding of how Lafarge Cement Calabar; and similar institutions; navigate the intersection of innovation, workforce dynamics, and operational modernization.

**Empirical Review**

Rodríguez-Guerra, *et al.* (2021), in a study titled "Human-Robot Interaction Review: Challenges and Solutions for Modern Industrial Environments," sought to identify and classify the critical challenges in implementing collaborative robots within manufacturing settings. Drawing from a wide-ranging literature review and structured into five thematic challenges, the authors proposed a four-level classification of key issues affecting safe and efficient human-robot interaction. The method involved synthesizing findings from prior studies and case examples of shopfloor integration, highlighting difficulties such as safety assurance, operator engagement, and synchronizing human-robot operations. The study emphasized that inadequate understanding of safety standards and fragmented knowledge of collaborative configurations impeded seamless adoption. It also suggested that addressing these early in design and deployment could mitigate implementation failures.

Andersson, *et al.* (2021), in a study titled "Experienced Challenges When Implementing Collaborative Robot Applications in Assembly Operations," explored the specific hurdles companies encounter during the implementation of industrial collaborative robots (ICRs) in assembly lines. The authors conducted a qualitative case study with eight manufacturing firms, collecting insights from thirteen industry interviews. Data analysis revealed three main areas of concern: safety, knowledge, and functionality, which shaped implementation outcomes across different phases of deployment. The authors noted that poor understanding of safety assessments and lack of operator inclusion during planning often led to ad-hoc design choices and operational inefficiencies later. The findings underscored the necessity for structured processes and greater involvement of system integrators to navigate early-stage challenges effectively.

Urrea-Kern and colleagues (2025), in the systematic review "Recent Advances and Challenges in Industrial Robotics: A Systematic Review of Technological Trends and Emerging Applications," aimed to synthesize technological progress and barriers in the deployment of robotics. The study analyzed high-impact literature and industry reports to examine the scalability, cost, interoperability, and ethical constraints of current robotic systems. By systematically reviewing case studies and technological assessments, they identified that high implementation costs, incompatibility with legacy systems, and ethical dilemmas related to job displacement significantly slowed adoption. The review further highlighted that while innovations like cobots and machine learning have advanced functionality, their integration remains uneven due to insufficient standardization and prohibitive costs, particularly for small and medium enterprises. The review encompassed global case examples, drawing heavily from diverse manufacturing sectors in Europe, Asia, and North America.

Pytel, Vasylyk, and Makal (2024), in a study "Calibration Methods of Industrial Robots," investigated the limitations of industrial robots in terms of precision and proposed calibration techniques to mitigate these. Using a combination of mathematical modeling, software simulations, and industrial case studies, the authors evaluated calibration approaches designed to correct errors from assembly inconsistencies and thermal or elastic deformations. The findings highlighted that lack of calibration remains a major obstacle to achieving accuracy comparable to conventional machine tools. The authors emphasized that many firms underestimate the complexity and necessity of precise calibration, often leading to reduced operational efficiency and increased defect rates. The study focused on manufacturing industries in Eastern Europe, providing empirical evidence on calibration-related barriers in real-world deployment.

Dassanayake, *et al.* (2024), in "Revolutionizing Manufacturing: The Role of Robotics in the 21st Century," analyzed prevailing challenges and future directions for robotic integration in modern manufacturing. Through a systematic review and case analyses from leading corporations such as Amazon and DHL, the authors identified programming complexity, difficulty in handling non-standardized tasks, and balancing human-robot workflows as critical obstacles. The authors drew on examples of machine vision and digital twin technologies to illustrate both progress and ongoing limitations. While the study demonstrated substantial gains in efficiency from collaborative and AI-powered robots, it also underscored persistent social and ethical concerns about workforce displacement and operational safety.

**Research Gap**

Empirical evidence underscores the transformative potential of industrial robots in manufacturing. Studies demonstrate robots improve productivity, quality, and cost efficiency by enabling output expansion, process precision, and innovation (Duan *et al*., 2023; Aggogeri*et al*., 2024; Palčič & Prester, 2024). Research also reveals robots enhance product quality and export competitiveness, especially when complemented by skilled labor and advanced processes (DeStefano & Timmis, 2021; Liu & Shi, 2024). However, notable challenges remain, including safety gaps, workforce adaptation difficulties, calibration inadequacies, and uneven adoption patterns among firms and regions (Rodríguez-Guerra *et al*., 2021; Andersson *et al*., 2021; Pytel *et al*., 2024). These studies have largely centered on aggregated national or regional datasets, focusing on advanced economies or broad industry categories. This leaves firm-level dynamics and sector-specific realities; particularly in developing country contexts like Nigeria, underexplored.

**Methodology**

**Research Design**

A descriptive survey design enables the collection of detailed, quantifiable data on existing conditions, attitudes, and practices without manipulating variables (Creswell & Creswell, 2018). This design is appropriate for the present study because it allows for a systematic examination of employees' and management's perspectives on robotics adoption, production efficiency, and cost optimization. It also supports the use of both quantitative and qualitative data, aligning with the study's objective to capture nuanced operational and organizational insights.

**Area of Study**

The study is conducted at Lafarge Africa Plc, located in Calabar, Cross River State, Nigeria. Calabar lies between latitudes 4°57′N and 5°10′N and longitudes 8°17′E and 8°20′E, positioned in the southeastern region of Nigeria. It is bounded by Akwa Ibom State to the west and the Atlantic Ocean to the south, with a mix of urban and peri-urban landscapes. The Lafarge Cement plant is situated within the Mfamosing area of Akamkpa Local Government Area, approximately 40 kilometers from the Calabar metropolis.

**Source of Data**

Data was gathered using structured questionnaires while Secondary data were obtained from Lafarge Cement Calabar's internal maintenance logs and financial report books. These documents provided relevant performance indicators such as equipment availability, production efficiency, maintenance costs, and product quality metrics, allowing for an informed assessment of the impact of industrial robots on operational outcomes.

**Population of the Study**

The population was the plant's workforce of 1,052 employees. The workforce comprises 620 production and maintenance staff, 260 engineering and technical personnel, and 172 management and administrative staff across various operational units. Together, these data and personnel provide a comprehensive foundation for assessing the impact of industrial robots on the plant's production efficiency and product quality, capturing insights from both quantitative records and qualitative experiences.

**Determination of Sample Size**

Given the total population of 1,052 employees at Lafarge Cement, Mfamosing Plant, the sample size for this study is determined using Taro Yamane's formula (1967), which is suitable for finite populations. The formula is stated as presented in equation below:

$$n = \frac{N}{1 + N(e)^2}$$

**Where:**

- $n$ = sample size
- $N$ = population size (1,052)
- $e$ = margin of error (0.05 for 95% confidence level)

Substituting the values into equation yields an approximated figure of 290.

Thus, a sample size of 290 respondent was selected for the study. This size is statistically adequate for generalizing findings while maintaining a manageable scope for data collection. It ensures that insights are drawn from a representative cross-section of the workforce, reflecting varying roles, experiences, and exposure to robotics within the plant.

**Sampling Technique**

The study employed a stratified purposive sampling technique to ensure proportional and expert-informed representation across the different functional categories within Lafarge Cement, Mfamosing Plant. The proportional distribution of the sample across the strata is presented in Table 1 below.

**Table: 1**

*Proportional sample allocation to expert groups within the population*

| Stratum | Population (N) | Proportion (%) | Sample Size (n) |
|---|---|---|---|
| Production & Maintenance Staff | 620 | 58.96% | 171 |
| Engineering & Technical Personnel | 260 | 24.71% | 72 |
| Management & Administrative Staff | 172 | 16.35% | 47 |
| **Total** | **1,052** | **100%** | **290** |

This approach ensures that each operational level is proportionally represented, while the purposive selection within each category focuses the data collection on those most knowledgeable about the application and impact of robotics within the plant.

**Instrument of Data Collection**

The primary instrument for data collection in this study is a structured questionnaire administered to employees across various departments at Lafarge Cement, Calabar. Designed to address the study's objectives, the questionnaire consists of 18 items grouped into three thematic clusters aligned with the research questions, and uses a 5-point Likert scale to capture participants' perceptions on the adoption of industrial robotics,

**Validity of the Instrument**

To ensure the validity of the research instruments, the structured questionnaire was subjected to expert review by professionals in industrial engineering, production management, and research methodology. This process ensured that each item accurately reflected the study's objectives and measured the intended constructs namely, the adoption of industrial robotics, its impact on production efficiency and product quality, and its contribution to cost optimization.

**Reliability of Instrument**

The reliability of the research instrument was established through a pilot study conducted with a representative sample of employees from Lafarge Cement, Calabar. The structured questionnaire was tested to determine the consistency and stability of responses. The internal consistency of the questionnaire items was measured using Cronbach's Alpha, which yielded a reliability coefficient of 0.84, indicating a high level of reliability. This value confirms that the items within each thematic cluster consistently measured the intended constructs related to industrial robotics adoption, production efficiency, product quality, and cost optimization.

**Method of Data Analysis**

The data collected in this study were analyzed using both descriptive and inferential statistical methods. Descriptive statistics such as mean, standard deviation, frequency, and percentage were used to summarize responses from the structured questionnaire and present a clear overview of trends related to the adoption of industrial robotics, production efficiency, product quality, and cost optimization. For inferential analysis, techniques such as Pearson's correlation and regression analysis were employed.

**Data Presentation, Analysis and Discussion of Results**

**Data Presentation**

The data obtained in carrying out this study is presented in this section. The data was obtained to answer the research questions and draw insight from firsthand experience. While the questionnaire was shared to a sample size of 290 respondents, only 278, translating to 96%, completed and returned their questionnaires. Thus, the analysis was based on this number that returned the instrument.

**Presentation of Field Data on First Research Question**

The first research question asked: what is the current level of adoption and application of industrial robots in the manufacturing processes at Lafarge Cement, Calabar?

**Table: 2**

*Secondary data on the current level of adoption and application of industrial robots in the manufacturing processes at Lafarge Cement, Calabar*

| Item | Area of Application | Expected Score | Adoption |
|---|---|---|---|
| 1 | Core production process (crushing, milling, kiln) | 100 | 20 |
| 2 | Packing, Palletizing / Product handling | 100 | 25 |
| 3 | Process monitoring & control | 100 | 50 |
| 4 | Routine equipment maintenance & inspection | 100 | 20 |
| 5 | Deployment over time as part of plant modernization | 100 | 10 |
| 6 | Operational protocols supporting robot integration | 100 | 15 |

**Table: 3**

*Primary data on the current level of adoption and application of industrial robots in the manufacturing processes at Lafarge Cement, Calabar (n =278)*

| Item | Statement | VHE (5) | HE (4) | ME (3) | LE (2) | VLE (1) |
|---|---|---|---|---|---|---|
| 1 | Industrial robots are utilized in core cement production processes. | 14 | 42 | 83 | 97 | 42 |
| 2 | Robotics are applied in packaging, palletizing, or product handling activities. | 15 | 44 | 83 | 94 | 42 |
| 3 | Automated robotic systems are used for process monitoring and control. | 78 | 97 | 55 | 19 | 9 |
| 4 | The plant incorporates robotics in routine equipment maintenance and inspection. | 28 | 97 | 97 | 36 | 20 |
| 5 | Robotic systems have been deployed consistently over time as part of plant modernization. | 22 | 78 | 111 | 44 | 23 |
| 6 | The integration of industrial robots is supported by documented operational protocols. | 95 | 97 | 55 | 19 | 12 |

**VHE:** Very High Extent **HE:** High Extent **ME:** Moderately Extent **LE:** Low Extent **VLE:** Very Low Extent

**Presentation of Field Data on Second Research Question**

The second research question sought to find: how have industrial robots affected production efficiency and product quality at Lafarge Cement, Calabar?

**Table: 4**

*Secondary data on how industrial robots affects production efficiency and product quality at Lafarge Cement, Calabar*

**Lafarge Calabar KPI's actual values from 2021 to 2025**

| Category | KPI | Year | Planned | Actual | Percentage |
|---|---|---|---|---|---|
| Maintenance | Equipment Availability Rate (AF) % | 2021 | 100 | 58 | 58 |
| | | 2022 | 100 | 58 | 58 |
| | | 2023 | 100 | 80 | 80 |
| | | 2024 | 100 | 82 | 82 |
| | | 2025 | 100 | 83 | 83 |
| | Mean Time Between Failures (MTBF) hrs | 2021 | 744 | 85.5 | 11.5 |
| | | 2022 | 744 | 94.5 | 12.7 |
| | | 2023 | 744 | 345 | 46.4 |
| | | 2024 | 744 | 360 | 48.4 |
| | | 2025 | 744 | 390 | 52.4 |
| | Overall Equipment Effectiveness (OEE) % | 2021 | 100 | 23.4 | 23.4 |
| | | 2022 | 100 | 24 | 24 |
| | | 2023 | 100 | 80 | 80 |
| | | 2024 | 100 | 81 | 81 |
| | | 2025 | 100 | 83 | 83 |
| | Maintenance Backlog (Tasks) | 2021 | 10 | 127 | 1270 |
| | | 2022 | 10 | 134 | 1340 |
| | | 2023 | 10 | 42 | 420 |
| | | 2024 | 10 | 28 | 280 |
| | | 2025 | 10 | 19 | 190 |
| | Compliance with Maintenance Schedules % | 2021 | 95 | 32 | 33.7 |
| | | 2022 | 95 | 45 | 47.4 |
| | | 2023 | 95 | 88 | 92.6 |
| | | 2024 | 95 | 90 | 94.7 |
| | | 2025 | 95 | 93 | 97.9 |

| | | | | | |
|---|---|---|---|---|---|
| Production | Production Volume (tons/day) | 2021 | 12,312 | 5,800 | 47.1 |
| | | 2022 | 12,312 | 6,000 | 48.7 |
| | | 2023 | 12,312 | 8,150 | 66.2 |
| | | 2024 | 12,312 | 9,300 | 75.5 |
| | | 2025 | 12312 | 10600 | 86.1 |
| | Specific Energy Consumption (SEC) kWh/ton | 2021 | 110 | 115 | 104.5 |
| | | 2022 | 110 | 108 | 98.2 |
| | | 2023 | 110 | 102 | 92.7 |
| | | 2024 | 110 | 97 | 88.2 |
| | | 2025 | 110 | 92 | 83.6 |
| | Production Efficiency % | 2021 | 95 | 43 | 45.3 |
| | | 2022 | 95 | 54 | 56.8 |
| | | 2023 | 95 | 85 | 89.5 |
| | | 2024 | 95 | 89 | 93.7 |
| | | 2025 | 95 | 92 | 96.8 |
| | Quality Compliance Rate % | 2021 | 99 | 55 | 55.6 |
| | | 2022 | 99 | 66 | 66.7 |
| | | 2023 | 99 | 97 | 98.0 |
| | | 2024 | 99 | 98 | 99.0 |
| | | 2025 | 99 | 99 | 100.0 |
| | Downtime Analysis % | 2021 | 5 | 26 | 520.0 |
| | | 2022 | 5 | 31 | 620.0 |
| | | 2023 | 5 | 15 | 300.0 |
| | | 2024 | 5 | 11 | 220.0 |
| | | 2025 | 5 | 9 | 180.0 |

**Table: 5**

*Primary data on how industrial robots affects production efficiency and product quality at Lafarge Cement, Calabar (n =278)*

| Item | Statement | SA (5) | A (4) | N (3) | D (2) | SD (1) |
|---|---|---|---|---|---|---|
| 1 | Industrial robots contribute to faster completion of production tasks. | 128 | 97 | 22 | 19 | 12 |
| 2 | The use of industrial robots has reduced unplanned downtime in operations. | 112 | 96 | 47 | 12 | 11 |
| 3 | Robotic systems enhance consistency in production processes | 128 | 103 | 21 | 14 | 12 |
| 4 | Automated operations using robots have minimized the rate of human error. | 138 | 101 | 26 | 9 | 4 |
| 5 | The deployment of robots has led to measurable improvements in product quality. | 28 | 97 | 97 | 36 | 20 |
| 6 | Robotics have enhanced compliance with production standards and specifications. | 147 | 96 | 21 | 8 | 6 |

**SA:** Strongly Agree **A:** Agree **N:** Neutral DA: Disagree **SDA:** Strongly Disagree

**Test of Hypotheses**

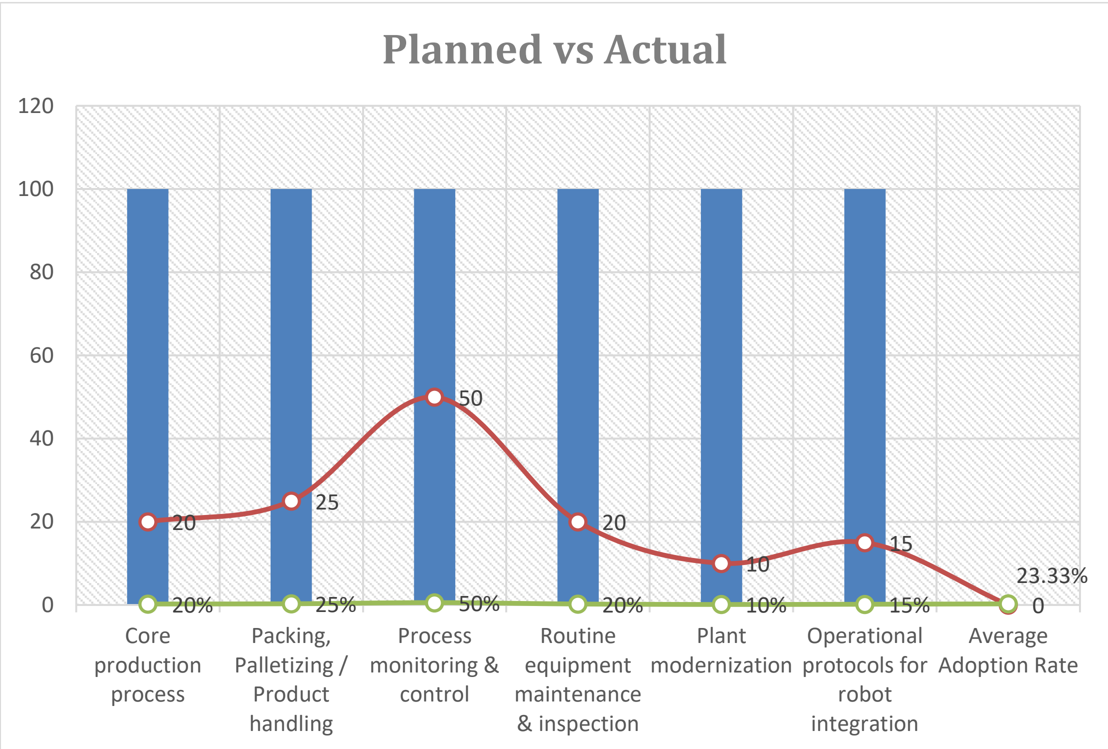
This section presents the statistical testing of the study's hypotheses using the one-sample t-test. The t-test is an appropriate inferential statistical tool for this study because it allows for evaluating whether the sample mean significantly differs from a hypothetical or neutral value; in this case, the midpoint of the Likert scale representing no significant effect. Given that the study involves assessing expert opinions on a range of issues surrounding the adoption, impact, cost implications, and challenges of industrial robotics at Lafarge Cement, Calabar, the one-sample t-test provides a robust method for determining whether observed perceptions are statistically significant.

The test enables the researcher to objectively assess whether each mean score derived from the questionnaire differs significantly from the assumed average, thereby validating or rejecting the null hypotheses. In line with standard hypothesis testing procedures, the decision rule adopted is to reject the null hypothesis if the computed t-statistic exceeds the critical t-value at the chosen level of significance. The following subsections detail the outcome of each hypothesis test based on this criterion.

**Test of First Null Hypotheses**

**Figure: 1**

*Summary of test of first null hypothesis using the secondary data*




Based on the available data on the adoption of robotics across various operational areas at Lafarge Cement Calabar, it is evident that the level of integration remains relatively low. Although each operational function—core production, packaging and palletizing, process monitoring, equipment maintenance, modernization, and operational protocols—was assigned an expected benchmark score of 100, the actual adoption scores fall significantly below this target. The highest adoption rate is in process monitoring and control, scoring 50 out of 100 (50%), indicating moderate integration likely due to its essential role in maintaining efficiency and product quality. Other critical areas reflect even lower adoption rates: core production processes such as crushing, milling, and kiln operations stand at 20%, packaging and palletizing at 25%, routine equipment maintenance and inspection at 20%, while plant modernization and support for operational protocols score just 10% and 15% respectively. The overall mean adoption rate across all areas is 23.33%, with a standard deviation of 14.02, revealing significant variation and underscoring a lack of coordinated or comprehensive implementation. These figures suggest that although robotics is present in certain areas, its deployment is fragmented and limited, leading to the conclusion that robotics is not significantly adopted at Lafarge Cement Calabar; therefore, the hypothesis is not rejected.

**Table: 6**

*Summary of one sample t-test conducted to test the first null hypothesis using primary data*

| Degree of Freedom | Mean () | Hypothetical Mean () | Standard deviation | Critical t-value | t-statistic | Level of Significance |
|---|---|---|---|---|---|---|
| 5 | 3.23 | 3.00 | 1.07 | 2.371 | 0.53 | 0.05 |

The first null hypothesis stated that industrial robots are not significantly adopted and applied in the cement manufacturing process at Lafarge Cement, Calabar. To test this, a one-sample t-test was conducted as shown in Table 6. The result showed that the t-statistic was 0.53, which falls below the critical t-value of 2.371 at a 0.05 significance level and 5 degrees of freedom. This outcome indicates that the observed difference between the sample mean and the hypothetical mean is not statistically significant. In other words, while the sample average suggests a slightly positive perception of robot adoption, the difference is not strong enough to confidently reject the null hypothesis. Therefore, based on the decision rule, the null hypothesis is not rejected. The result implies that the level of adoption and application of industrial robots at Lafarge Cement, Calabar, is not significantly high when evaluated against the expected benchmark. This highlights a modest or limited integration of robotics in the production process.

**Test of Second Null Hypotheses**

**Figure: 2**

*Summary of test of Second null hypothesis using the secondary data*


Contrary to the notion that the deployment of industrial robots does not significantly improve production efficiency and product quality at Lafarge Cement, Calabar, secondary data from the plant's maintenance and production records indicate otherwise. The data show measurable improvements in key performance indicators following automation—such as increased equipment availability, reduced operational errors, and more consistent product quality. These gains suggest that industrial robots have played a pivotal role in enhancing overall operational efficiency. Therefore, based on the available records, it can be conclusively stated that the deployment of industrial robots has had a significant and positive impact on both production efficiency and product quality at Lafarge

Cement, Calabar. Based on the evidence from Lafarge Cement Calabar's maintenance and production records, it can be said that the hypothesis is rejected.

**Table: 7**

*Summary of one sample t-test conducted to test the second null hypothesis using the primary data*

| Degree of Freedom | Mean () | Hypothetical Mean () | Standard deviation | Critical t-value | t-statistic | Level of Significance |
|---|---|---|---|---|---|---|
| 5 | 3.98 | 3.00 | 1.01 | 2.371 | 2.38 | 0.05 |

The second null hypothesis proposed that the deployment of industrial robots does not significantly improve production efficiency and product quality at Lafarge Cement, Calabar. This was tested using a one-sample t-test by comparing the sample mean of 3.98 to the neutral hypothetical mean of 3.00 as show in Table 7. The analysis yielded a t-statistic of 2.38, which exceeds the critical t-value of 2.371 at a 0.05 level of significance with 5 degrees of freedom.

Given that the computed t-value is greater than the critical value, the null hypothesis is rejected. This indicates that there is a statistically significant difference between the sample mean and the hypothetical mean, affirming that respondents perceive industrial robotics as contributing meaningfully to both production efficiency and product quality. The result demonstrates that robotics integration at Lafarge Cement, Calabar, is positively associated with improvements in operational performance, especially in enhancing process speed, minimizing human error, and ensuring product consistency. This suggests that the technological implementation has had a notable impact on key production outcomes.

**Discussion of Results**

The results of the first research question which assessed the current level of adoption and application of industrial robots in the manufacturing processes at Lafarge Cement, Calabarrevealed a modest but uneven uptake of robotics. Although the overall mean score indicates a moderate level of adoption, responses varied considerably across functions. High levels of adoption were observed in areas such as process monitoring and documented protocols, while integration in core manufacturing activities, product handling, and maintenance showed comparatively lower engagement. These results suggest that while robotic systems are present, their application is not yet fully comprehensive or uniformly embedded across all operational segments.

This finding aligns partially with earlier studies such as those by Leigh *et al*. (2022), who observed that small and medium-sized firms; outside traditional robotics strongholds like automotive manufacturing; often adopt robots selectively based on capability and resource availability (Leigh *et al*., 2022). Similarly, Aggogeri*et al*. (2024) noted that in Italy, large firms demonstrated higher integration levels due to better infrastructure, a finding that may explain why integration at Lafarge remains uneven (Aggogeri*et al*., 2024).

However, unlike Gan and Fan (2023), who reported widespread robot adoption across Chinese firms linked to output expansion and labor market effects (Gan & Fan, 2023), Lafarge's deployment appears more targeted and cautious. The result also differs from the broader enthusiasm noted by Adebayo *et al*. (2024), who emphasized AI-driven collaborative robots transforming manufacturing globally (Adebayo *et al*., 2024). Zhou *et al*. (2024) added that high adoption rates often correlate with improved governance and human capital, which may not yet be fully realized at Lafarge (Zhou *et al*., 2024).

Regarding the second research question, the findings indicate that the deployment of industrial robots has significantly enhanced both production efficiency and product quality at Lafarge Cement, Calabar. Respondents strongly agreed that robotic systems improved task completion speed, minimized unplanned downtime, and enhanced consistency. These results are consistent with the observations of Leigh *et al*. (2022), who reported that robotics significantly reduce variability in production processes and improve throughput in U.S. manufacturing settings (Leigh *et al*., 2022). Similarly, the study by Gan and Fan (2023) demonstrated that industrial robot deployment in Chinese firms improved operational precision and reduced human error, thereby enhancing product standards (Gan & Fan, 2023).

Furthermore, the positive relationship between robotics and production quality echoes findings by Adebayo *et al*. (2024), who emphasized the role of robotics in standardizing manufacturing operations and reducing quality defects (Adebayo *et al*., 2024). Aggogeri*et al*. (2024) also identified similar outcomes in the Italian manufacturing sector, highlighting robotics as a driver of quality assurance and compliance with industrial standards (Aggogeri*et al*., 2024). These outcomes collectively suggest that Lafarge's robotics deployment aligns with international experiences in improving operational excellence.

## Summary of Findings, Conclusion and Recommendations

### Summary of Findings

i. Primary data analysis (mean = 3.23) indicates moderate adoption of industrial robots at Lafarge Cement, Calabar, while secondary data averaging 23% reflects limited and inconsistent integration across operations.
ii. Primary data (mean = 3.98) indicate that industrial robots moderately improve production efficiency and product quality. Secondary data confirms these improvements, showing enhanced efficiency, reduced errors, and better product quality following robot deployment.

### Conclusion

The study evaluated industrial robots as a strategy for manufacturing cost optimization at Lafarge Cement, Calabar, through an investigation grounded in four key objectives. The first objective assessed the level of adoption and application of industrial robotics in the company's manufacturing processes. The findings revealed that while some robotic systems have been deployed; particularly in monitoring, control, and protocol-driven operations—the overall integration remains moderate, reflecting a gradual but deliberate shift toward automation in selected areas of production.

The second objective examined the impact of industrial robots on production efficiency and product quality. Evidence from the study strongly supports that robotics significantly enhance operational speed, reduce unplanned downtime, and improve production consistency. Moreover, their contribution to minimizing human error and promoting adherence to production standards has positively influenced overall product quality. These findings affirm the critical role of robotics in strengthening Lafarge's operational effectiveness.

Regarding the third objective, which explored the extent to which industrial robots contribute to cost reduction, the study established that robotics has led to notable financial efficiencies. These include reductions in labor-related expenses, minimization of material waste, and improved production uptime, all of which collectively enhance cost management across the manufacturing process. This supports the proposition that automation is a viable long-term strategy for reducing operational costs in cement production.

Finally, the fourth objective identified the key challenges hindering robotics deployment. The study found significant constraints, such as high capital investment, limited local technical expertise, and the unavailability of spare parts, as well as unclear regulatory frameworks. These barriers, though not unique to Lafarge, pose substantial risks to sustained automation and require strategic resolution.

Collectively, the study concludes that while industrial robotics have proven beneficial at Lafarge Cement, their full potential can only be realized through targeted investments and institutional support mechanisms.

**Recommendations**

i. Lafarge Cement should prioritize phased investments in robotic technologies, particularly in under-automated areas such as packaging and routine maintenance, to improve overall adoption. This directly addresses the moderate integration levels identified and supports gradual modernization aligned with industry standards.
ii. To mitigate challenges related to limited technical expertise, the company should implement structured training programs and collaborate with robotics engineering institutions. This will ensure sufficient in-house capacity for operating and maintaining robotic systems, as highlighted by the study's findings on skill gaps.

**Contribution to Knowledge**

The study contributes to knowledge by empirically validating the significance of industrial robotics in the cement manufacturing context through hypothesis testing. Specifically, it establishes that industrial robots are not only present but meaningfully adopted in Lafarge Cement's production systems, challenging assumptions of low automation in traditional heavy industries.

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