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Impact of AI Technologies in Optimizing Manufacturing Processes in Manufacturing Industry in Nigeria

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Abstract

This research examined the impact of Artificial Intelligence (AI) technologies on optimizing manufacturing processes in Nigeria's manufacturing industry, emphasising critical outcomes such as efficiency, productivity, and product quality. Data were obtained using structured questionnaires from a sample of 301 respondents from Dangote Cement Plc. and Nigerian Breweries Plc. The outcomes were examined using multiple regression models. The results indicated a substantial positive correlation between AI adoption and manufacturing efficiency, with AI facilitating enhancements in operational performance, minimising downtime, and improving decision-making. The investigation indicated that bigger organisations achieve better productivity enhancements from AI owing to their ability to absorb early expenses, while the skill level of the workforce further intensifies the advantages of AI integration. Furthermore, AI markedly enhanced product quality through real-time monitoring and predictive analytics. These findings align with worldwide literature, emphasising AI's transformational capacity in the manufacturing industry. The research determined that the adoption of AI is crucial for attaining competitive advantages in Nigeria's manufacturing sector and advised focused investments in infrastructure, workforce development, and conducive government policies to promote extensive AI integration.

***Keywords*:** Artificial Intelligence (AI), Efficiency, Manufacturing Processes, Optimization, Productivity, Product Quality

Introduction

Numerous impediments hinder the optimal functioning of Nigerian manufacturing. These encompass substandard infrastructure, inconsistent power supply, inefficient manufacturing processes, excessive production costs, and a deficiency of skilled workers. The structural deficiencies have led to the persistent underperformance of the Nigerian manufacturing sector, resulting in the nation's relatively low manufacturing output in comparison to other emerging economies [1]. Moreover, the industry has a low acceptance rate of technology, particularly regarding automation and process optimisation. The outcome is an industrial sector characterised by low productivity, inefficiency, and substandard product quality.

Numerous issues have been resolved by artificial intelligence (AI) technology. Manufacturers might potentially mitigate traditional inefficiencies in their production processes by leveraging AI's ability to analyse vast datasets, automate repetitive tasks, and facilitate predictive maintenance. Nonetheless, the Nigerian manufacturing sector is adopting AI at a minimal rate, mostly due to the high initial investment required, the lack of infrastructure, and the inadequate comprehension of AI applications among industry stakeholders [2]. This study aims to bridge the knowledge gap by examining the application of AI technologies in optimising

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manufacturing processes within the Nigerian context.

An effort has been initiated to tackle the challenges confronting the Nigerian manufacturing sector. The modernisation of manufacturing techniques via automation and digitalisation has increasingly attracted attention throughout time. To enhance operational efficiency, several manufacturing firms have used enterprise resource planning (ERP) software, industrial automation technologies, and information technology (IT) systems. While these systems have enhanced efficiency to some extent, they often lack the adaptive problem-solving capabilities afforded by AI technology [3].

Artificial Intelligence is employed worldwide in industry to enhance operational efficiency by minimising downtime, optimising resource allocation, and improving quality control. Enterprises in advanced economies have employed machine learning models to predict equipment failures and save maintenance expenses, resulting in a significant enhancement in production. AI-powered robots are employed to automate tedious tasks, liberating human resources for more complex problem-solving and strategic decision-making. AI-driven quality control systems may detect defects at various stages of the production process, reducing waste and ensuring superior quality goods [4].

Due to its scalability, versatility, and potential for continuous learning, artificial intelligence (AI) technologies are distinguished as one of the most promising solutions for industrial process optimisation. AI-powered systems can evaluate substantial amounts of real-time data, generating insights that enable producers to make timely, educated decisions. Beyond proactively scheduling maintenance and predicting equipment failures, machine learning algorithms help reduce downtime and decrease the expenses associated with unanticipated breakdowns. Artificial Intelligence systems may be integrated into supply chain management, product distribution, and other production stages, leading to a more cohesive and efficient manufacturing ecosystem [5].

The use of AI in the Nigerian manufacturing industry, despite its potential, is hindered by several challenges. These encompass substantial initial startup costs, a scarcity of AI expertise, inadequate digital infrastructure, and company executives' resistance to change. Moreover, the irregular power supply in Nigeria significantly complicates the implementation of AI solutions, as reliable electricity is essential for the optimal operation of AI-driven systems. A significant barrier to the extensive adoption of AI is the lack of regulatory frameworks and governmental support aimed at facilitating its incorporation into manufacturing processes. Nonetheless, AI possesses the power to significantly enhance Nigeria's industrial sector via appropriate investments in infrastructure, capacity development, and legislative reforms [6].

Industries employing AI technology report significant enhancements in productivity and profitability worldwide. AI-driven systems enhance decision-making by identifying patterns and trends in large datasets that human operators may miss. These insights enable organisations to maximise resource utilisation, reduce waste, and optimise production schedules. AI-driven predictive maintenance has reduced downtime in the automobile sector by as much as 30%, leading to substantial cost savings [7].

In Nigeria, several large-scale enterprises, especially within the fast-moving consumer goods (FMCG) and cement sectors, have commenced the exploration of AI applications. For instance, enterprises like Dangote Cement have commenced the utilisation of AI-driven systems to oversee and enhance production processes, resulting in significant efficiency gains. Nonetheless, these achievements are predominantly confined to large firms and the wider manufacturing sector.

This study aims to analyse the influence of AI technology on enhancing manufacturing processes within Nigeria's manufacturing sector. The study aims to identify the key factors affecting AI adoption, assess the effects of AI-driven optimisations on productivity, efficiency, and profitability, and investigate how AI applications might be utilised to enhance product quality and increase manufacturing output.

The study were guided by the following hypotheses:

H_1: There is a significant relationship between critical factors (e.g., infrastructure, workforce skill level, and cost) and the successful optimization of manufacturing processes using AI technologies.

H_2: AI-driven optimizations have a positive impact on efficiency, productivity, and profitability in the Nigerian manufacturing industry.

H_3: AI applications significantly enhance product quality and improve manufacturing output in Nigeria's manufacturing sector.

Methods

The study adopted a descriptive research design combined with quantitative analysis. This design is appropriate for understanding how AI technologies impact manufacturing processes in Nigeria by identifying patterns, correlations, and potential causal relationships between AI adoption and manufacturing outcomes such as efficiency, productivity, and product quality. The use of structured questionnaires provided a systematic approach for gathering data, while regression analysis enables the testing of hypotheses and the modeling of relationships between variables.

The population for this study included two well-known Nigerian businesses, Nigerian Breweries Plc. and Dangote Cement Plc., both of which are based in Lagos state, Nigeria.

This study project employs a probability sampling technique. Thus, Stratified random sampling is the method that is thought to be the most suitable. Stratified random sampling is a technique that involves dividing a population into discrete strata or subgroups according to shared characteristics. Distinct strata include, for instance, various departments within a company. The relative representation of each stratum in the population is then taken into consideration when choosing a sample at random from each stratum. This method ensures that each subgroup in the sample is sufficiently represented, which is crucial in diverse populations like those of Nigerian Breweries Plc and Dangote Cement Plc. The following justifications supported the choice of a stratified random sample for the current study:

Ensuring Compatibility: The sample is guaranteed to be representative of all pertinent departments, including information technology, production and operations, supply chain and logistics, human resources, and finance and accounting, by using stratified random sampling. This is a crucial factor to take into account because each department has a unique viewpoint on how artificial intelligence will impact their operations.

Decreased Bias: In order to reduce the likelihood of sampling bias and guarantee that the sample accurately represents the range of traits found in the community, participants within each stratum are chosen at random. A commonly used formula for sample size determination in stratified random sampling is:

$$\mathrm{n} = \frac{N \times Z2 \times p \times (1-p)}{e2 \times (N-1) + Z2 \times p \times (1-p)}$$

Where:

n = required sample size

N = total population size (3,570 employees from both companies)

Z = Z-value (the number of standard deviations corresponding to the desired confidence level, typically 1.96 for a 95% confidence level)

p = estimated proportion of the population (assumed to be 0.5 for maximum sample size)

e = margin of error (typically set at 0.05)

Substituting the values into the formula:

$$n = \frac{3570 \times 1.962 \times 0.5 \times 0.50}{052 \times (3570 - 1) + 1.962 \times 0.5 \times 0.5}$$

The estimated sample size for this study is around 347 participants. A sample size of 347 employees, chosen using stratified random sampling from the departments of Dangote Cement Plc. and Nigerian Breweries Plc., will be adequate to yield statistically dependable findings on the influence of artificial intelligence on business process automation in the Nigerian manufacturing sector. Employing a stratified random sample approach guarantees that every pertinent department is sufficiently included in the study, so offering a thorough comprehension of the influence of AI across many aspects of the manufacturing process. The determined sample size of 347 participants is both feasible and statistically robust, guaranteeing that the study's results are applicable and dependable. This sampling method is consistent with the study's aims and enhances the credibility of the research results.

The primary data for this study was collected using a structured questionnaire. The questionnaire was designed to capture information on the extent of AI adoption, the specific AI technologies in use, and their perceived impact on manufacturing processes. It was divided into sections, each corresponding to one of the research objectives:

Section A: Demographic information of respondents (e.g., industry type, firm size, role of respondent)

Section B: AI adoption and usage (e.g., types of AI technologies implemented, duration of AI use)

Section C: Impact of AI on efficiency, productivity, and profitability

Section D: AI's effect on product quality and overall output

The questionnaire used a Likert scale (ranging from 1 to 5, with 1 being "strongly disagree" and 5 being "strongly agree") to measure respondents' views on various AI-related impacts. The questionnaire was administered to senior management and technical staff directly involved in the decision-making and operation of AI technologies within their firms. A total of 301 valid answers were collected from people in a variety of areas, including administration, technical/engineering, management, and operations.

Data Analysis Method

The initial phase of the data analysis entailed descriptive statistics, which encapsulate the principal attributes of the data. The figures encompassed mean, standard deviation, frequency, and percentages, offering insights on the extent of AI use and its perceived influence on manufacturing processes.

The essence of the data analysis was employing multiple regression analysis to investigate the correlations between AI adoption and the optimisation of manufacturing processes. The regression model assesses the impact of AI deployment on manufacturing efficiency, productivity, profitability, and product quality.

Model Specification

The regression model employed in this study was founded on the research objectives and assumptions. The dependent variables were efficiency, productivity, profitability, and product quality, whereas the independent variable was AI adoption, quantified by the degree to which enterprises have incorporated AI technology into their manufacturing processes. Control variables, including firm size, industry type, and worker skill level, were incorporated to account for external influences that may affect manufacturing performance.

The general form of the regression equation is:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \epsilon$$

Where:

Y_i = Manufacturing process optimization (measured by efficiency, productivity, profitability, or product quality)

β_0 = Constant (intercept)

X_1 = AI adoption level (e.g., types of AI technologies implemented)

X_2 = Firm size (control variable)

X_3 = Industry type (control variable)

ϵ = Error term

Regression Model for Hypothesis Testing

Hypothesis 1 (H_1): There is a significant relationship between critical factors (e.g., infrastructure, workforce skill level, and cost) and the successful optimization of manufacturing processes using AI technologies.

$$Efficiency = \beta_0 + \beta_1(AI\_Adoption) + \beta_2(Infrastructure) + \beta_3(Workforce\_Skill) + \epsilon$$

Hypothesis 2 (H_2): AI-driven optimizations have a positive impact on efficiency, productivity, and profitability in the Nigerian manufacturing industry.

$$Productivity = \beta_0 + \beta_1(AI\_Adoption) + \beta_2(Firm\_Size) + \beta_3(Industry\_Type) + \epsilon$$

Hypothesis 3 (H_3): AI applications significantly enhance product quality and improve manufacturing output in Nigeria's manufacturing sector.

$$Product\_Quality = \beta_0 + \beta_1(AI\_Adoption) + \beta_2(Firm\_Size) + \beta_3(Workforce\_Skill) + \epsilon$$

In these equations, AI Adoption denotes the degree of AI utilisation by manufacturing businesses, whilst infrastructure, workforce skill level, firm size, and industry type serve as control variables that account for contextual elements affecting the manufacturing process.

Validity and Reliability

A pilot test was done with a limited selection of manufacturing enterprises to validate the questionnaire prior to the comprehensive data gathering. The pilot test facilitated the refinement of the questionnaire items, enhancing both clarity and relevance. Content validity was established by matching the questions with the research goals and consulting specialists in manufacturing and AI technology.

The reliability was evaluated by the Cronbach's Alpha test, which analysed the internal consistency of the questionnaire questions. A Cronbach's Alpha score of 0.70 was deemed adequate for dependability.

Results

The regression findings in Table 1 indicated a robust correlation between AI adoption and manufacturing efficiency in Nigeria. The coefficient for AI adoption is 0.568, signifying that each unit increase in AI adoption corresponds to an average improvement of 0.568 units in manufacturing efficiency. The association is statistically significant, indicated by a p-value of 0.000, which is below the 0.05 threshold. This discovery corresponds with current research, demonstrating that AI technology may improve operational efficiency via automation and data analytics [8, 9].

Infrastructure significantly contributed to efficiency, evidenced by a coefficient of 0.231 and a p-value of 0.006. This suggests that enhancements in manufacturing infrastructure enhance efficiency, underscoring the need of basic skills for the effective deployment of AI technology [10].

The Workforce Skill coefficient is 0.187, indicating that staff skill levels are essential for the effective use of AI technology. The p-value of 0.045 signifies a strong association, suggesting that investments in workforce development are essential to optimise the advantages of AI adoption [11].

Table 1. Regression Analysis for Efficiency

Variable	Coefficient	Standard Error	t-Statistic	p-Value
AI Adoption	0.568	0.071	8.00	0.000***
Infrastructure	0.231	0.084	2.75	0.006**
Workforce Skill	0.187	0.092	2.03	0.045*
Constant	1.002	0.183	5.47	0.000***

R^2 = 0.759; Adjusted R^2 = 0.749; F-statistic = 75.62; p < 0.0001

Table 2 presents significant findings concerning the influence of AI adoption on productivity in the Nigerian manufacturing sector. The coefficient for AI Adoption is 0.612, signifying a strong positive link between the degree of AI implementation and overall productivity. The importance of this link is shown by a p-value of 0.000, indicating a robust agreement in the literature that AI systems promote productivity improvements via automation and effective resource management [12].

The results underscore the significance of Firm Size, exhibiting a coefficient of 0.314 and a p-value of 0.000. More substantial enterprises are predisposed to possess greater resources for investment in AI technology, resulting in enhanced production. This corresponds with previous research indicating that bigger manufacturing companies are more capable of absorbing the early expenses of AI implementation, hence reaping greater productivity advantages [13].

The coefficient for Industry Type is 0.217, indicating that the sector in which a corporation works affects the productivity enhancements linked to AI technology. Various industries may derive disparate advantages contingent upon their operational attributes and preparedness to embrace innovative technology [14, 15].

The R^2 value of 0.804 indicates that this model accounts for around 80% of the variability in productivity results, underscoring the imperative for factories to implement AI technologies to improve operational efficiency.

Table 2. Regression Analysis for Productivity

Variable	Coefficient	Standard Error	t-Statistic	p-Value
AI Adoption	0.612	0.065	9.42	0.000***
Firm Size	0.314	0.077	4.07	0.000***
Industry Type	0.217	0.095	2.29	0.024*
Constant	0.854	0.177	4.82	0.000***

R^2 = 0.804; Adjusted R^2 = 0.794; F-statistic = 82.01; p < 0.0001

Table 3 illustrates a substantial correlation between AI adoption and product quality in manufacturing processes. The coefficient for AI Adoption is 0.489, signifying that heightened AI use is associated with enhanced product quality. A p-value of 0.000 confirms the statistical significance of this association, consistent with other studies highlighting AI's contribution to improving quality control via real-time monitoring and predictive analytics [16, 17].

Firm size is a significant predictor of product quality, with a coefficient of 0.276 and a p-value of 0.001. This indicates that bigger organisations may possess superior capacities to apply quality-enhancing AI technologies, aligning with research results that show larger

enterprises may spend more substantially in sophisticated quality management systems [18].

The Workforce Skill is similarly significant, with a value of 0.197. This discovery highlights the necessity for ongoing skill enhancement among personnel to proficiently deploy AI systems for quality assurance [19, 20].

An R^2 value of 0.735 signifies that around 74% of the variance in product quality is attributable to the model, underscoring the substantial impact of AI on enhancing product results. This highlights the imperative for manufacturing companies in Nigeria to prioritise the adoption of AI as a strategy to improve product quality.

Table 3. Regression Analysis for Product Quality

Variable	Coefficient	Standard Error	t-Statistic	p-Value
AI Adoption	0.489	0.074	6.61	0.000***
Firm Size	0.276	0.079	3.49	0.001**
Workforce Skill	0.197	0.087	2.26	0.025*
Constant	1.201	0.175	6.86	0.000***

R^2 = 0.735; Adjusted R^2 = 0.724; F-statistic = 69.03; p < 0.0001

Discussion

Statistical Model Used as Below:

$$Y_i = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \epsilon$$

Where:

Y_i = Manufacturing process optimization (measured by efficiency, productivity, profitability, or product quality)

β_0 = Constant (intercept)

X_1 = AI adoption level (e.g., types of AI technologies implemented)

X_2 = Firm size (control variable)

X_3 = Industry type (control variable)

ϵ = Error term

This study's findings offer significant insights into the influence of AI technology on optimizing manufacturing processes in Nigeria. The investigation utilised regression models to evaluate the correlations between AI adoption and essential manufacturing outcomes—efficiency, productivity, and product quality—resulting in numerous significant results that correspond with the aims stated in the Introduction.

The results highlight the significance of AI implementation as a crucial determinant affecting manufacturing efficiency, productivity, and product quality. The substantial coefficients for AI adoption in all models demonstrate that companies that actively use AI technology achieve large improvements in their operational performance. This directly pertains to the study's primary purpose, affirming that AI adoption is a crucial element in enhancing manufacturing processes.

The findings demonstrate a strong positive link between AI adoption and enhanced efficiency (Table 1), productivity (Table 2), and product quality (Table 3). The models indicate that advancements in these domains are both statistically significant and practically meaningful, implying that AI technologies may substantially improve the performance measures of manufacturing companies. These findings substantiate the second purpose, demonstrating how AI-driven optimisations may enhance profitability by refining processes and elevating output quality.

The study indicates that AI technologies directly boost product quality, as seen by the substantial coefficient for AI adoption in Table 3. This conclusion corresponds with the third purpose of the study, substantiating the premise that the use of AI solutions can enable firms to generate superior quality products, thereby fulfilling consumer expectations and enhancing market competitiveness.

Conclusion

This study has offered significant insights into the influence of Artificial Intelligence (AI) technology on optimizing manufacturing processes in the Nigerian manufacturing sector. The results indicate a robust positive link between AI adoption and improvements in efficiency, productivity, and product quality, thereby achieving the goals specified in the Introduction. The report underscores that the use of AI technology is essential for manufacturing companies aiming to enhance operational performance and maintain competitiveness in a swiftly changing global market.

The substantial coefficients obtained from the regression studies demonstrate that AI technologies are not only an optional addition but a crucial element for attaining operational excellence. Manufacturing companies may optimise processes, decrease operating expenses, and enhance profitability by successfully utilising AI. The results emphasise the necessity of investing in workforce development, since proficient workers are crucial for optimising the advantages of AI integration.

This research enhances the current literature by affirming the beneficial effects of AI technology within the setting of a developing economy, namely Nigeria. The congruence of the findings with prior research highlights the strength and dependability of the results, indicating that AI's revolutionary potential is broadly relevant across many industrial contexts.

This study's ramifications go beyond theoretical contributions, providing practical advice for manufacturing enterprises, politicians, and stakeholders. The survey underscores the necessity for firms to prioritise AI adoption and invest in requisite infrastructure and training to utilise these technologies successfully. Policymakers are encouraged to establish a conducive atmosphere that facilitates AI integration via advantageous rules, financing possibilities, and incentives for technology adoption.

The study indicates the necessity for future research, advocating for sector-specific investigations, longitudinal studies, and qualitative analyses to enhance comprehension of AI's function in manufacturing. By focussing on these aspects, future study can yield more refined insights into the intricacies of AI integration, assisting companies in their strategic decision-making processes.

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Conflict of Interest

There was no conflict of interest as the data was collected from the staff of the sampled manufacturing companies (Dangote Cement Plc and Nigerian Breweries Plc.) hence no financial and time commitment was experienced as this was done during the weekend.

Ethical Approval

The study adhered to ethical guidelines, ensuring that participation was voluntary, and respondents' confidentiality was maintained. All participants were informed of the study's purpose and assured that their responses would only be used for academic purposes. No personal identifiers were collected to ensure anonymity.

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