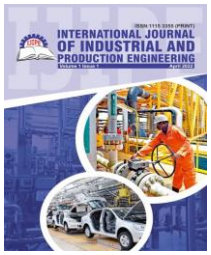

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Adoption of Smart Factories in Nigeria: Problems, Obstacles, Remedies and Opportunities

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Abstract: The manufacturing sector in Nigeria, which includes industries such as food and beverages, textiles, chemicals, and automotive, faces significant challenges due to outdated infrastructure, limited access to advanced technologies, and a shortage of skilled labour. Foreign Direct Investment (FDI) plays a crucial role in improving sector performance, highlighting the need for strategic interventions. While some firms still use traditional methods, others explore smart manufacturing technologies. Early adopters of smart manufacturing demonstrate potential benefits and obstacles, such as inadequate infrastructure, high costs, limited access to advanced technologies, economic barriers, skills gaps, brain drain, inadequate government support, and regulatory hurdles. To address these issues, the paper recommends developing infrastructure, forming partnerships with tech firms, providing government subsidies and grants, encouraging private investment, and enhancing workforce development through training and collaboration with educational institutions. Policy recommendations include creating supportive regulations and establishing industry standards to promote smart manufacturing. The paper also examines successful implementations of smart factories in other countries and suggests initiating pilot projects in Nigeria to demonstrate feasibility and benefits. Adopting smart manufacturing technologies is forecasted to positively impact Nigeria's economy by increasing productivity, efficiency, and competitiveness in the manufacturing sector.

Keywords: Smart factories, Industry 4.0, Manufacturing automation, Industrial Internet of Things (IIoT), Technological Adoption

1.0 Introduction

Smart factories, as a pivotal component of the fourth industrial revolution (Industry 4.0)(Onuoha et al., 2022), transform manufacturing by integrating digital technologies to establish interconnected production environments (Ita, 2023). These factories improve efficiency, flexibility, and responsiveness through real-time communication among machines, systems, and humans (Ita, 2023). The utilization of technologies such as AI, Big Data, and Digital Twins is essential for smart manufacturing (Okeagu & Mgbemena, 2022; Lu et al., 2020). Overcoming obstacles like user resistance and cost barriers necessitates a profound comprehension of the advantages of smart factories for successful implementation (Sofić et al., 2022). Tailored strategies for small and medium-sized enterprises (SMEs) are crucial for effective adoption in Nigeria (Sofić et al., 2022). The incorporation of digital technologies like IoT, AI, and 5G in manufacturing significantly enhances operational performance and sustainability (Mgbemena et al., 2023; Mgbemena & Okeagu, 2023). Empirical studies indicate that factors such

as innovation, skilled human capital, and exposure to export markets drive the adoption of digital technologies in manufacturing (Avenyo, 2024). The digital transformation of manufacturing enterprises is advanced through the application of technologies like IoT, data encryption, and digital twins. Understanding the influence of the digital economy on technological innovation is vital for the progress of manufacturing enterprises (Ugwu, 2023). The integration of digital technologies such as blockchain and cloud computing enhances trust mechanisms and operational efficiency in manufacturing processes (Rane & Huang, 2023; Nwamekwe, et. al., 2020). Emphatically, the implementation of smart factories in Nigeria demands a strategic approach that considers the benefits, challenges, and customized solutions for successful integration in the evolving manufacturing sector.

The implementation of smart factories in Nigeria offers a promising opportunity for advancing manufacturing practices. To facilitate this transition successfully, it is essential to assess the current state of technology adoption, identify obstacles, and propose solutions. Also, the development of a hybrid model for implementing smart production factories within the industry 4.0 framework offers innovative solutions to industrial challenges (Samani & Saghafi, 2023). By synthesizing these research findings, a solid foundation can be established to guide the adoption of smart factories in Nigeria.

This study aims to explore the challenges and opportunities associated with adopting smart factories in Nigeria. By examining the current state of technology adoption, identifying obstacles, and proposing solutions, the research seeks to provide a comprehensive framework for facilitating the transition to smart manufacturing in Nigeria by answering the following questions:

1. What is the current state of smart factory adoption in Nigeria?
2. What are the primary obstacles hindering the adoption of smart factories in Nigeria?
3. What strategies can be implemented to overcome these obstacles and promote the adoption of smart factories in Nigeria?

1.1 Structure of the Paper

The paper is structured into several sections: Introduction, Current State of Smart Factories in Nigeria, Problems and Obstacles, Remedies and Strategies, Case Studies and Best Practices, Future Prospects and Opportunities, and Conclusion.

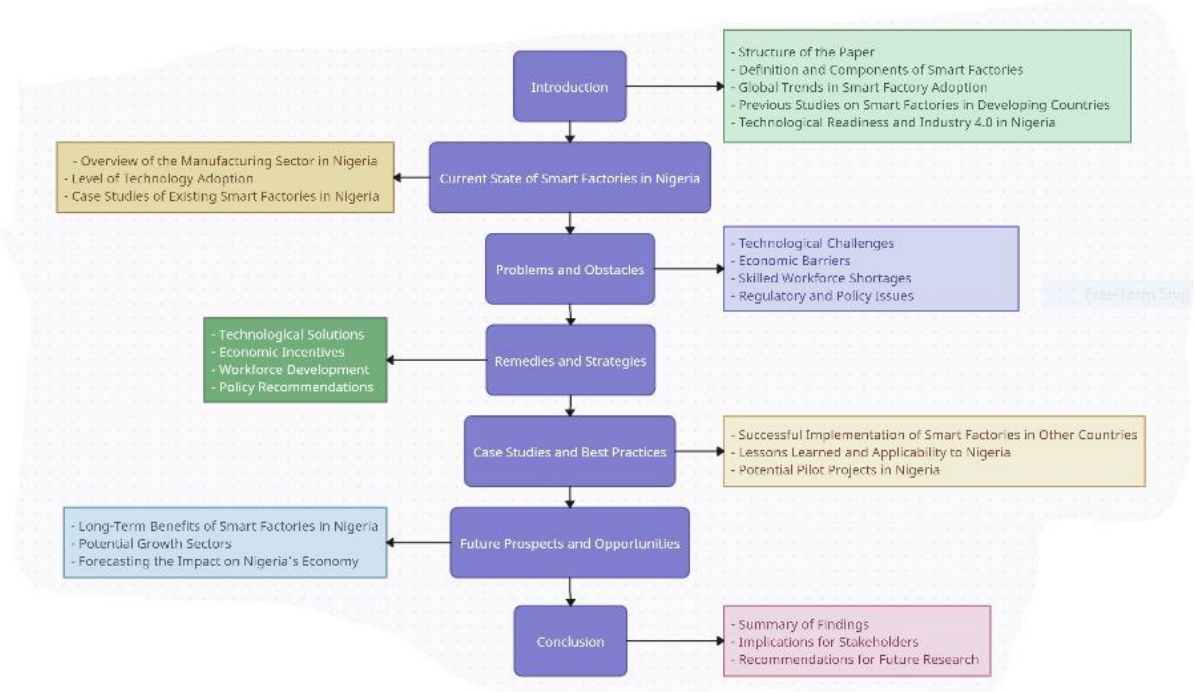

Figure 1: Paper Structure

This structure should comprehensively cover the topic and provide a clear framework for analysing the adoption of smart factories in Nigeria.

1.2 Definition and Components of Smart Factories

Smart factories represent a significant advancement in manufacturing, integrating technologies like IoT, AI, ML, and big data analytics to create automated and self-optimizing production environments (Mohamed et al., 2019). These factories rely on cyber-physical systems, advanced sensors, connectivity, and data analytics platforms for real-time monitoring and optimization of manufacturing processes (Mohamed et al., 2019). Leveraging Industry 4.0 capabilities, smart factories enhance energy efficiency and sustainability (Mohamed et al., 2019). Challenges in embedding big data solutions in smart factories are addressed through empirical investigations. The adoption of smart factories in SMEs is influenced by perceived benefits, organizational readiness, and external pressures. A hybrid model for smart production within the Industry 4.0 framework offers innovative solutions to industrial challenges (Samani & Saghafi, 2023). Understanding the barriers and strategic approaches through empirical investigation is crucial for smart factory advancement (Bagherian, 2024). By exploring these references, a comprehensive understanding of the technologies, challenges, and opportunities associated with smart factories can be developed.

1.3 Global Trends in Smart Factory Adoption

The global trend towards smart factory adoption is rapidly gaining momentum as manufacturers strive to enhance productivity, flexibility, and competitiveness (Oke, 2018). Leading industrial nations like Germany, the United States, and Japan are spearheading this transformation through substantial investments in technology and infrastructure (Oke, 2018). This shift towards smart manufacturing is reshaping traditional production paradigms and driving innovation in industrial practices globally.

1.4 Previous Studies on Smart Factories in Developing Countries

Research on smart factories in developing countries underscores challenges such as technological readiness, infrastructure deficits, and workforce skills gaps (Hamja et al., 2021). However, successful case studies in countries like India and Brazil demonstrate that strategic investments and supportive policies can facilitate the adoption of smart manufacturing technologies (Hamja et al., 2021). These findings align with the notion that advancements in technology and infrastructure play a pivotal role in overcoming barriers to smart factory implementation (Hamja et al., 2021). By investing in technology and fostering supportive policies, developing countries can bridge the gap in technological readiness and infrastructure deficits, paving the way for the successful adoption of smart manufacturing practices.

1.5 Technological Readiness and Industry 4.0 in Nigeria

Nigeria's journey towards Industry 4.0 faces a landscape of both opportunities and challenges. While there is a growing recognition of the potential advantages of smart factories, significant gaps persist in infrastructure, skills, and investment (Tan & Taeihagh, 2020). These deficiencies pose obstacles to the seamless transition to smart manufacturing in the country. By addressing these gaps through targeted investments and policy frameworks, Nigeria can bridge the divide in technological readiness and infrastructure deficits, thereby paving the way for a successful transition to smart manufacturing practices.

2. Current State of Smart Factories in Nigeria

2.1 Overview of the Manufacturing Sector in Nigeria

Nigeria's manufacturing sector, which includes industries such as food and beverages, textiles, chemicals, and automotive, faces significant challenges such as outdated infrastructure, limited access to advanced technologies, and a shortage of skilled labour (Idoko & Taiga, 2018). Research on the effect of Foreign Direct Investment (FDI) on manufacturing sector output growth in Nigeria highlights the importance of external investments in driving sectoral performance (Idoko & Taiga, 2018). Studies on the impact of infrastructure development on industrial growth emphasize the critical role of infrastructure in enhancing manufacturing value added in Nigeria (Edeme et al., 2020). These findings emphasize the need for strategic interventions to address infrastructure deficits and skill shortages to bolster the vibrancy and competitiveness of Nigeria's manufacturing sector.

2.2 Level of Technology Adoption

Technology adoption in Nigeria's manufacturing sector is characterized by disparities, with some firms still reliant on traditional methods while others are beginning to explore and implement smart manufacturing technologies (Okereke et al., 2021). Research on the impact of digitalization on firm performance in the manufacturing sector of Nigeria reveals significant positive effects, indicating a shift towards more innovative practices (Okereke et al., 2021). Studies on the effect of financial sector performance on manufacturing sector growth in Nigeria underscore the interconnectedness of these sectors and the importance of financial stability for industrial development (Asaleye et al., 2018). These findings highlight the evolving landscape of technology adoption in Nigeria's manufacturing sector and the need for strategic interventions to bridge the gap between traditional and smart manufacturing practices.

2.3 Case Studies of Existing Smart Factories in Nigeria

The adoption of smart factory technologies in Nigeria presents a varied landscape, with early adopters showcasing a mix of successes and challenges. These firms have demonstrated the potential benefits of smart manufacturing, such as enhanced efficiency and product quality, while also shedding light on significant obstacles that need to be addressed (Kalsoom et al., 2020). Research on sensor technologies in the context of smart factories emphasizes the evolution of Industry 4.0 and the critical role of sensors in smart manufacturing (Kalsoom et al., 2020). Studies on the capabilities of smart factory solution suppliers emphasized the importance of assessing firms' competencies in smart factory operations and technologies (Cha, 2023). These findings highlight the dynamic nature of technology adoption in Nigeria's manufacturing sector and the need for strategic interventions to navigate the complexities of transitioning to smart manufacturing practices.

3. Problems and Obstacles

3.1 Technological Challenges

3.1.1 Infrastructure deficiencies

Nigeria's manufacturing sector grapples with inadequate infrastructure, particularly in terms of reliable power supply and high-speed internet connectivity, which poses challenges for smart factory operations. Research on the impact of infrastructure development on industrial growth in Nigeria underscores the critical role of infrastructure in enhancing manufacturing value added and sectoral performance. Consequently, the COVID-19 pandemic has contributed to supply chain disruptions and a large percentage of Nigerian manufacturing firms are material-constrained (Orji et al.,2022), and this necessitates the need to have an established structure for a multi-tier supply chain network. Additionally, studies on the effect of transport infrastructure on agricultural sector performance highlight the positive relationship between road transport infrastructure and agricultural development in Nigeria. These findings underscore the importance of addressing infrastructure deficiencies to support the successful deployment and utilization of advanced manufacturing technologies in Nigeria.

3.1.2 Limited Access to Advanced Technologies

The high cost and limited availability of advanced manufacturing technologies present significant barriers to their adoption in Nigeria's manufacturing sector. Many firms face challenges due to financial constraints and a lack of technical expertise required to invest in and maintain these technologies. Research on barriers to supply chain sustainability innovation highlights the importance of overcoming challenges related to skill sets and experience in driving sustainability initiatives (Gupta et al., 2020). Additionally, studies on factors affecting the sustainable adoption of e-health technology in developing countries emphasize the role of barriers such as resistance by professionals and low technical expertise in hindering technology adoption (Zayyad & Toycan, 2018). These findings underscore the critical need for addressing financial and technical barriers to facilitate the adoption of advanced manufacturing technologies in Nigeria.

3.2 Economic Barriers

3.2.1 High Initial Costs

The significant initial investment required for smart factory technologies poses a challenge for many firms in Nigeria's manufacturing sector. The costs associated with acquiring and installing advanced equipment, as well as the need for continuous maintenance and upgrades, can be prohibitive, impeding the widespread adoption of these

technologies. Research highlights the importance of sensor technologies in smart factories within the context of Industry 4.0, emphasizing the critical role sensors play in enhancing manufacturing processes (Kalsoom et al., 2020). Furthermore, studies on smart factory solution suppliers stress the necessity of assessing firms' competencies in smart factory operations and technologies (Cha, 2023). These findings underscore the financial obstacles faced by firms in embracing advanced manufacturing technologies and emphasize the requirement for strategic interventions to overcome these barriers.

3.2.2 Uncertain ROI (Return on Investment)

Research in the realm of smart factory technologies often encounters uncertainties regarding the return on investment, particularly in the short term. Firms may exhibit hesitancy in investing in new technologies without clear evidence of their potential benefits and cost savings (Kalsoom et al., 2020). To address this challenge, future research should focus on expanding the scope of the study, exploring additional case studies, and examining the long-term impact of smart factory adoption. By delving into the interplay of smart production systems, big data analytics, and cyber-physical systems, researchers can gain deeper insights into the transformative potential of Industry 4.0 technologies. Investigating the requirements, emerging technologies, and applications of smart cities can provide valuable insights for integrating smart technologies in urban environments. Exploring the current status and future outlook of artificial intelligence in advanced manufacturing can shed light on the evolving landscape of smart factories and their impact on the manufacturing sector (Buba et al., 2019). By understanding user resistance, challenges, and opportunities of smart factory adoption, researchers can develop comprehensive strategies for promoting technological advancement. Through a systematic review of the challenges and opportunities of implementing Industry 4.0 in public shareholding manufacturing companies, researchers can identify key success factors and barriers to smart factory adoption (Cha, 2023).

3.3 Skilled Workforce Shortages

3.3.1 Lack of Training and Education

The adoption of smart factory technologies in Nigeria is impeded by a significant skills gap in the workforce, with many workers lacking the necessary training and education to operate and maintain these advanced manufacturing technologies. This skills gap acts as a major barrier to the adoption of advanced manufacturing methods in the country (Kalsoom et al., 2020). Research on the role of humans and industrial robots in smart factories emphasized the evolving landscape of technology integration and the progress made in related technologies (Evjemo et al., 2020). Studies on the capabilities of smart factory solution suppliers stress the necessity of assessing firms' competencies in smart factory operations and technologies (Cha, 2023). These findings highlight the critical need for addressing the skills gap in Nigeria's workforce to facilitate the successful adoption of advanced manufacturing technologies.

3.3.2 Brain Drain

The brain drain phenomenon in Nigeria, characterized by the emigration of skilled professionals seeking opportunities abroad, exacerbates the existing skills shortage and undermines efforts to cultivate a proficient workforce for smart manufacturing (Chidebe, 2023). Research on workforce shortages in healthcare sectors highlights the adverse impact of such shortages on patient care and safety, emphasizing the need for strategic recommendations to address healthcare needs (Khan, 2023). Additionally, studies on the impact of Artificial Intelligence and Machine Learning on workforce skills in developing countries underscore the importance of understanding the implications of technological advancements on workforce capabilities and economic mobility (Muhammad et al., 2023). These findings underscore the critical need for addressing the brain drain and skills shortage in Nigeria to foster the development of a competent workforce capable of embracing advanced manufacturing technologies.

3.4 Regulatory and Policy Issues

3.4.1 Inadequate Government Support

Government support for the adoption of smart factory technologies in Nigeria is limited, with a lack of targeted policies and incentives to encourage firms to invest in and adopt advanced manufacturing technologies (Osakwe et al., 2019). The absence of supportive government initiatives hinders the progress of smart manufacturing in the country. Research on the barriers to the adoption of smart government services emphasizes the importance of

overcoming obstacles to the implementation of smart initiatives. Additionally, studies on the impact of governance structure characteristics on smart city project success underscore the significance of effective governance in driving successful outcomes (Liu et al., 2019). These findings underscore the critical role of government support and policies in fostering the adoption of advanced manufacturing technologies in Nigeria.

3.4.2 Regulatory Hurdles

Regulatory barriers, including complex and outdated regulations, can impede the adoption of new technologies, such as smart manufacturing, in Nigeria. Streamlining and updating regulations is essential to create a more conducive environment for the implementation of advanced manufacturing technologies. Research on the impacts of the Internet of Things (IoT) on supply chains emphasizes the need for frameworks that support technological advancements in warehousing and logistics (Mostafa et al., 2019). Additionally, studies on blockchain-enabled supply chain traceability implementations highlight the importance of regulatory frameworks in ensuring the authenticity and traceability of products (Dasaklis et al., 2022). These findings underscore the necessity of addressing regulatory barriers to foster the adoption of smart manufacturing technologies in Nigeria. By addressing regulatory challenges, Nigeria can create an environment conducive to the implementation of advanced manufacturing technologies.

4. Remedies and Strategies

4.1 Technological Solutions

4.1.1 Infrastructure development

Investing in infrastructure development, particularly in power and connectivity, is crucial for supporting smart factory operations in Nigeria. However, regulatory barriers, including complex and outdated regulations, can impede the adoption of new technologies. Streamlining and updating regulations is necessary to create a more conducive environment for smart manufacturing (Liu et al., 2020). Public-private partnerships (PPPs) can play a key role in financing and implementing these improvements, facilitating the integration of advanced manufacturing technologies in Nigeria (Liu et al., 2020). Research on the impacts of the Internet of Things (IoT) on supply chains emphasizes the need for frameworks that support technological advancements in warehousing and logistics (Mostafa et al., 2019). Additionally, studies on blockchain-enabled supply chain traceability implementations highlight the importance of regulatory frameworks in ensuring the authenticity and traceability of products (Dasaklis et al., 2022). These findings underscore the necessity of addressing regulatory barriers and investing in infrastructure to foster the adoption of smart manufacturing technologies in Nigeria.

4.1.2 Partnerships with Tech Firms

Collaborating with technology firms can help manufacturing companies in Nigeria access advanced technologies and expertise, facilitating the transfer of knowledge and skills necessary to overcome technological barriers (Frempong et al., 2021). Research on the impacts of the Internet of Things (IoT) on supply chains emphasizes the need for frameworks that support technological advancements in warehousing and logistics (Mostafa et al., 2019). Additionally, studies on blockchain-enabled supply chain traceability implementations highlight the importance of regulatory frameworks in ensuring the authenticity and traceability of products (Dasaklis et al., 2022). These findings underscore the critical role of partnerships with technology firms in enhancing the capabilities of manufacturing companies to adopt and leverage advanced technologies for improved operational efficiency and competitiveness.

4.2 Economic Incentives

4.2.1 Government Subsidies and Grants

Government subsidies and grants are crucial in reducing financial barriers for firms and encouraging investment in smart factory technologies. The uncertainty surrounding the return on investment, particularly in the short term, can hinder firms from adopting new technologies without clear evidence of their potential benefits and cost savings (Kalsoom et al., 2020). To tackle this challenge, targeted financial support through government subsidies can help offset the high initial costs associated with implementing advanced technologies, thus making them more accessible to firms across various industries. Furthermore, government subsidies have been shown to positively influence enterprise innovation, technological adoption, and corporate sustainability, underscoring the significance of financial incentives in yielding favourable outcomes across various sectors (Aliu, 2023; Wang et

al., 2021). It is worth noting that these subsidies and grants serve as essential tools for alleviating financial obstacles, encouraging investment in smart factory technologies, and promoting innovation and sustainability across industries. Future research should continue to explore the effects of government subsidies on enterprise performance, technology adoption, and sustainability, offering valuable insights for policymakers, industry leaders, and researchers aiming to advance technological progress and environmental sustainability through financial incentives (Bello, 2024). By scrutinizing the role of government subsidies in shaping industry practices, fostering innovation, and driving sustainable development, researchers can contribute to the ongoing discourse on the importance of financial support mechanisms in generating positive outcomes in the business and environmental realms (Ejidike et al., 2019).

4.2.2 Encouraging Private Investment

Investing in smart factory technologies can indeed be a significant financial commitment for firms, and the uncertainty surrounding the return on investment, especially in the short term, can act as a deterrent. However, creating a favourable investment climate through government subsidies and grants can help alleviate the financial burden on firms and encourage investment in smart factory technologies (Alohan et al., 2019). By promoting policies that incentivize investment in technology and innovation, governments can stimulate the adoption of smart factory technologies, ultimately driving economic growth and competitiveness in the manufacturing sector (Ifeanyi-Obi, 2020). Streamlining and updating regulations is necessary to create a more conducive environment for smart manufacturing (Kalsoom et al., 2020). Public-private partnerships (PPPs) can play a key role in financing and implementing these improvements, facilitating the integration of advanced manufacturing technologies in Nigeria (Kalsoom et al., 2020). Collaborating with technology firms can help manufacturing companies access advanced technologies and expertise, enabling firms to overcome technological barriers. These partnerships can facilitate the transfer of knowledge and skills necessary for firms to adopt and leverage advanced technologies for improved operational efficiency and competitiveness (Fauska & Kniežová, 2023).

4.3 Workforce Development

4.3.1 Training Programs and Certifications

Developing training programs and certification schemes can help bridge the skills gap in Nigeria's workforce. Collaboration between industry, government, and educational institutions is essential for creating a workforce equipped with the necessary skills and knowledge. Research on the impacts of the Internet of Things (IoT) on supply chains emphasizes the need for frameworks that support technological advancements in warehousing and logistics (Mostafa et al., 2019). Additionally, studies on blockchain-enabled supply chain traceability implementations highlight the importance of regulatory frameworks in ensuring the authenticity and traceability of products (Dasaklis et al., 2022). These findings underscore the critical role of partnerships with technology firms in enhancing the capabilities of manufacturing companies to adopt and leverage advanced technologies for improved operational efficiency and competitiveness. This comprehensive approach involving infrastructure investment, regulatory reform, and skills development can pave the way for the successful adoption of smart manufacturing technologies in Nigeria.

4.3.2 Collaboration with Educational Institutions

Partnerships with universities and technical schools are essential in enhancing the quality and relevance of education and training programs for smart manufacturing. Collaborations between academia and industry ensure that curricula are aligned with industry needs, preparing students effectively for careers in smart manufacturing (Agbo et al., 2020). These partnerships facilitate the integration of cutting-edge technologies like smart supply chain systems and IoT into educational programs, providing valuable insights for policymakers and practitioners in the manufacturing industry (Lee, 2023). By leveraging smart technologies such as multi-access edge computing and blockchain, universities can design smart manufacturing systems that significantly improve processing times, aligning education with industry advancements (Lee et al., 2023). Through comprehensive frameworks and assessments, institutions can develop smart campuses that cater to the needs of modern industries, ensuring that students are equipped with the necessary skills for the evolving manufacturing landscape. Emphasizing learning styles and environmental characteristics in higher education, particularly in smart education systems, can further enhance the effectiveness of educational initiatives in preparing students for smart manufacturing careers. By addressing barriers and enablers to adopting smart technologies, universities can play a pivotal role in fostering innovation and sustainability in the manufacturing sector.

4.4 Policy Recommendations

4.4.1 Developing Supportive Regulations

Reforming regulatory frameworks to support the adoption of smart factory technologies is crucial for fostering innovation and technological advancement in manufacturing. By updating existing regulations, eliminating unnecessary barriers, and introducing policies that incentivize innovation, organizations can navigate the complexities of integrating smart technologies into their operations (Xing et al., 2022). These regulatory changes are essential to align industry practices with technological advancements, ensuring that companies can leverage smart factory solutions effectively (Meng et al., 2018). By addressing barriers to adopting industrial big data solutions and enhancing energy efficiency in smart factories, regulatory frameworks can create an environment conducive to technological adoption and sustainable practices (Onaolapo & Oyewole, 2018; Meng et al., 2018). Collaborative efforts between policymakers, industry stakeholders, and researchers are necessary to develop regulatory frameworks that promote the seamless integration of smart technologies in manufacturing processes (Solms, 2020). Through the implementation of regulatory technology (RegTech) and the development of frameworks for joint energy provisioning and manufacturing scheduling, organizations can streamline compliance processes and optimize their operations in smart factory environments (Solms, 2020). These initiatives are vital for driving the digital transformation of manufacturing industries and ensuring that smart factory technologies are adopted effectively and sustainably.

4.4.2 Establishing Industry Standards

Establishing industry standards for smart manufacturing is crucial for providing a structured framework that guides firms in adopting smart factory technologies effectively. These standards play a vital role in ensuring consistency, quality, and interoperability within the manufacturing sector, thereby facilitating the widespread adoption of smart factory technologies (Xing et al., 2022). By setting industry standards, organizations can align their practices with best practices, enhancing operational efficiency and competitiveness (Das, 2024). These standards also promote innovation and technology adoption by providing a common ground for companies to develop and implement smart manufacturing solutions. Collaborative efforts between industry stakeholders, policymakers, and researchers are essential in developing and implementing these standards to drive the digital transformation of manufacturing industries. By adhering to established industry standards, firms can streamline their processes, improve product quality, and enhance overall performance in the smart manufacturing landscape.

5. Case Studies and Best Practices

5.1 Successful Implementation of Smart Factories in Other Countries

Examining successful implementations of smart factories in other countries can offer valuable insights into Nigeria's industrial landscape. Case studies from various countries can provide a wealth of best practices and strategies that can be tailored to suit the Nigerian context (Imran et al., 2018; Sjödin et al., 2018; Sajadieh et al., 2022). By analysing how other nations have successfully integrated smart factory technologies, Nigeria can learn from their experiences and adapt proven methodologies to enhance its manufacturing sector (Imran et al., 2018; Sjödin et al., 2018; Sajadieh et al., 2022). These case studies can shed light on the challenges faced, the strategies employed, and the outcomes achieved, offering a roadmap for Nigerian industries to follow in their smart manufacturing journey (Imran et al., 2018; Sjödin et al., 2018; Sajadieh et al., 2022). By leveraging the lessons learned from global implementations of smart factories, Nigeria can accelerate its adoption of Industry 4.0 technologies and drive innovation and growth in its manufacturing sector.

5.2 Lessons Learned and Applicability to Nigeria

Examining successful implementations of smart factories in other countries can provide valuable insights for Nigeria's industrial development. By studying case studies from diverse nations, Nigeria can gain valuable lessons on overcoming common challenges and obstacles in adopting smart factory technologies (Tan & Taeihagh, 2020; Rahmani, 2024). Understanding key success factors from these implementations is crucial for Nigeria to tailor strategies that align with its unique context and promote the adoption of smart factories (Tan & Taeihagh, 2020; Rahmani, 2024). By analysing the experiences of other countries, Nigeria can identify best practices, innovative approaches, and effective strategies that can be adapted to enhance its manufacturing sector and drive technological advancement (Tan & Taeihagh, 2020; Rahmani, 2024). Leveraging these insights can help Nigeria

navigate the complexities of smart factory adoption, optimize processes, and foster sustainable growth in its industrial landscape

5.3 Potential Pilot Projects in Nigeria

Initiating pilot projects in Nigeria to showcase the feasibility and benefits of smart factory technologies is a strategic approach to drive technological advancement in the country's manufacturing sector. By leveraging insights from successful implementations in other countries, such as those highlighted in various case studies (Kalsoom et al., 2020; Sjödin et al., 2018; Samani & Saghafi, 2023), Nigeria can gain valuable lessons on overcoming challenges and obstacles in adopting smart factory technologies. These pilot projects can serve as practical models for wider adoption, offering tangible examples of how to address specific challenges unique to Nigeria's industrial landscape. By identifying key success factors from global implementations and tailoring strategies to the Nigerian context, these pilot projects can pave the way for the effective integration of smart factory technologies in the country (Kalsoom et al., 2020; Sjödin et al., 2018; Samani & Saghafi, 2023). Through these initiatives, Nigeria can demonstrate the transformative potential of smart factories, foster innovation, and drive sustainable growth in its manufacturing industry.

6. Future Prospects and Opportunities

6.1 Long-Term Benefits of Smart Factories in Nigeria

The implementation of smart factories in Nigeria has the potential to significantly transform the country's manufacturing sector, leading to increased productivity, efficiency, and competitiveness. Smart factories can act as drivers for economic growth, job creation, and the enhancement of product and service quality in the long run. Drawing insights from successful smart factory implementations in other nations can provide valuable lessons for Nigeria in overcoming common challenges and barriers (Kalsoom et al., 2020; Fauska & Kniežová, 2023). Nigeria needs to identify key success factors and develop strategies tailored to its specific context to encourage the widespread adoption of smart factory technologies (Lv & Zhu, 2022). Launching pilot projects can showcase the feasibility and advantages of smart factory technologies, serving as practical models for broader adoption and offering concrete examples of how to address unique challenges within Nigeria's industrial landscape (Evjemo et al., 2020; Cha, 2023; Sajadieh et al., 2022). By harnessing the transformative capabilities of smart factories, Nigeria can drive innovation, promote sustainable growth, and position itself at the forefront of technological advancement in the manufacturing industry

6.2 Potential Growth Sectors

The identification of sectors with high growth potential and significant opportunities for smart factory adoption is crucial for Nigeria's industrial development. By leveraging insights from successful smart factory implementations in other countries, Nigeria can gain valuable lessons on overcoming common challenges and barriers (Meng et al., 2018; Fauska & Kniežová, 2023; Xing et al., 2022). Understanding key success factors from global implementations and tailoring strategies to the Nigerian context can encourage widespread adoption of smart factory technologies (Rahmani, 2024; Lv & Zhu, 2022; Onyeneke et al., 2024). Initiating pilot projects can showcase the feasibility and advantages of smart factory technologies, serving as practical models for broader adoption and offering concrete examples of how to address unique challenges within Nigeria's industrial landscape. By harnessing the transformative capabilities of smart factories, Nigeria can drive innovation, promote sustainable growth, and position itself at the forefront of technological advancement in the manufacturing industry.

6.3 Forecasting the Impact on Nigeria’s Economy

Assessing the potential economic impact of smart factory adoption is crucial for guiding policy and investment decisions in Nigeria's manufacturing sector. By forecasting the benefits, such as increased productivity, job creation, and economic growth, a compelling case can be made for supporting the transition to smart manufacturing (Fauska & Kniežová, 2023). Understanding the economic implications of smart factory technologies can provide valuable insights into the transformative power they hold for Nigeria's industrial landscape. Leveraging the findings from studies on Industry 4.0 technologies, blockchain applications, and anomaly detection in smart factories can offer a comprehensive understanding of the economic benefits and challenges associated with smart manufacturing (Wu et al., 2022). By evaluating the economic viability of smart factory investments and exploring the potential economic, social, and operational impacts of smart factories, Nigeria can strategically position itself to harness the full potential of these technologies for sustainable economic

development (Zhang, 2023). Through a systematic review of the economic benefits of smart city initiatives and the assessment of IT availability risks in smart factory networks, Nigeria can pave the way for informed decision-making and strategic investments in smart manufacturing (Khan, 2023). By examining the economic, social, and environmental effects of smart factories, Nigeria can create a roadmap for leveraging these technologies to drive economic growth, job creation, and sustainable development in the manufacturing sector.

7. Conclusion

Summary of Findings

This study highlights the significant challenges and opportunities associated with adopting smart factories in Nigeria. While there are numerous obstacles, strategic investments in infrastructure, workforce development, and supportive policies can facilitate the transition to smart manufacturing.

The integration of smart factories in Nigeria offers both challenges and opportunities for the country's manufacturing sector. Despite existing obstacles, targeted investments in infrastructure, workforce development, and supportive policies can significantly aid in the shift towards smart manufacturing. By evaluating the potential economic ramifications of smart factory implementation, policymakers and investors can make well-informed decisions that promote sustainable growth and innovation within Nigeria's industrial sphere. Understanding the implications of smart factory technologies can provide crucial insights into their transformative capacity for Nigeria's economic advancement. Drawing on research on Industry 4.0 technologies, blockchain applications, and anomaly detection in smart factories can provide a comprehensive understanding of the economic advantages and challenges linked with smart manufacturing. Through a meticulous assessment of the economic feasibility of smart factory investments and an exploration of the potential economic, social, and operational impacts of smart factories, Nigeria can strategically position herself to leverage these technologies fully for sustainable economic progress. By conducting a systematic review of the economic benefits of smart city initiatives and evaluating IT availability risks in smart factory networks, Nigeria can develop a roadmap to utilize these technologies to propel economic growth, job creation, and sustainable development in the manufacturing sector.

Implications for Stakeholders

The findings have important implications for various stakeholders, including policymakers, industry leaders, and educational institutions. Collaborative efforts are necessary to create an enabling environment for smart factory adoption and to harness the full potential of Industry 4.0. The adoption of smart factories in Nigeria presents a spectrum of challenges and opportunities that have far-reaching implications for various stakeholders. Collaborative efforts are essential to create an enabling environment for smart factory adoption and to fully harness the potential of Industry 4.0 technologies. Understanding the challenges and opportunities associated with smart factory adoption is crucial for guiding strategic decisions and investments in Nigeria's manufacturing sector. By leveraging the capabilities of Industry 4.0 to enhance energy efficiency and process innovation, Nigeria can position herself for sustainable growth and technological advancement. The integration of smart factory design principles, such as information and communication integration, can pave the way for enhanced operational efficiency and productivity. Moreover, exploring smart contract-based access control schemes and RFID network planning can further optimize processes and improve visibility in smart factory environments. By addressing user resistance and focusing on small and medium-sized enterprises, Nigeria can ensure a smoother transition to smart manufacturing and maximize the benefits of Industry 4.0 technologies. Also, understanding the challenges and opportunities of implementing Industry 4.0 can provide valuable insights for Nigeria's public shareholding manufacturing companies. Through a systematic review of the applications of multi-agent reinforcement learning and the role of leaders in technology adoption, Nigeria can develop a roadmap towards successful smart factory implementation. By exploring the potential environmental benefits of smart factories and securing IT/OT links for low-power IoT devices, Nigeria can drive sustainable practices and ensure the security of smart manufacturing systems. Furthermore, assessing the economic impact of smart factory adoption and forecasting the benefits can guide policy decisions and investments, ultimately leading to enhanced productivity, job creation, and economic growth in Nigeria's manufacturing sector. This comprehensive approach to understanding the challenges and opportunities of smart factory adoption underscores the importance of collaborative efforts and strategic investments to propel Nigeria towards a technologically advanced and sustainable future.

Recommendations for Future Research

Future research should focus on expanding the scope of the study, exploring additional case studies, and examining the long-term impact of smart factory adoption in Nigeria. By delving into the interplay of smart production systems, big data analytics, cyber-physical systems, and the potential business process management improvements, researchers can gain deeper insights into the transformative potential of Industry 4.0 technologies. Additionally, investigating the requirements, emerging technologies, applications, challenges, and future aspects of smart cities can provide valuable insights into the integration of smart technologies in urban environments. Exploring the current status and future outlook of artificial intelligence in advanced manufacturing can shed light on the evolving landscape of smart factories and their impact on the manufacturing sector. Furthermore, a bibliometric network analysis of recent publications on digital agriculture can offer strategic themes and evolution structures for future research in the agricultural sector.

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