Impact of Maintenance Engineering on Sustainable Asset Management: A Case from Nigeria

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Abstract: This study examines the impact of maintenance engineering on sustainable asset management, with a particular focus on the Nigerian context. Maintenance engineering is essential for prolonging asset longevity, improving operational efficiency, and supporting environmental sustainability. Despite its importance, Nigeria faces significant challenges including inadequate funding, lack of skilled personnel, weak policy frameworks, and a reactive maintenance culture that undermines asset performance and accelerates deterioration. Globally, maintenance frameworks are evolving through the adoption of advanced technologies such as predictive maintenance, digital tools, and sustainability-driven strategies. While Nigeria is gradually aligning with these global trends, gaps remain in policy development, capacity building, technology adoption, and sustainable financing. This review highlights these challenges and gaps, and recommends strategic reforms, investment in human capital, and integration of modern technologies to enhance maintenance effectiveness. Future directions emphasize renewable energy integration, smart technologies, water conservation, and Industry 4.0 innovations as pathways to modernize maintenance management in Nigeria. Collaborative efforts among government, industry, and academia are critical to institutionalizing best practices and fostering a proactive maintenance culture that supports sustainable development. The findings provide valuable insights for policymakers, practitioners, and researchers intending to improve asset management and sustainability outcomes in Nigeria and similar developing contexts.

Keywords*: Maintenance Engineering, Sustainable Asset Management, Asset Longevity, Maintenance Culture, Nigeria, Predictive Maintenance, Infrastructure Maintenance, Capacity Building, Sustainability Strategies, Technology Adoption.*

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I. INTRODUCTION

- *Background on Sustainable Asset Management and Maintenance Engineering*

Sustainable asset management is the coordinated activity of an organization to realize value from assets in a way that balances economic, environmental, and social factors over the asset lifecycle. Maintenance engineering, as a core discipline within this framework, ensures that physical assets are maintained in a manner that supports reliability, safety, and efficiency while minimizing negative environmental impacts.

Schröder and Baumgartner (2010) emphasize that sustainable plant asset management requires a holistic approach, integrating sustainability principles into every phase of the asset lifecycle—from investment and operation to decommissioning. Their framework advocates for the minimization of resource inputs (such as materials and energy), reduction of emissions, and enhancement of social responsibility, including workplace safety and stakeholder

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engagement. They further highlight the importance of life-cycle costing and performance measurement systems as tools for aligning maintenance activities with sustainability objectives.

Recent advancements in asset management underscore the necessity of consolidating asset data, conducting risk assessments, and developing robust asset registers to support informed decision-making and sustainable service delivery. Asset management frameworks now routinely incorporate asset condition assessments, risk profiles, and long-term financial planning to ensure that maintenance and renewal activities are both economically and environmentally sustainable.

Van Dongen (2021) also points out that maintenance engineering optimizes asset management by leveraging technological advances in monitoring, planning, and defect prediction, thus enabling organizations to create value by balancing performance, reliability, and sustainability throughout the asset's life.

➢ *Importance of Maintenance in Nigerian Infrastructure*

In the Nigerian context, maintenance engineering is particularly significant due to the country's aging infrastructure, rapid urbanization, and resource constraints. The effective management and maintenance of infrastructure are crucial for extending asset lifespan, reducing operational costs, and ensuring reliable service delivery.

Ogunsemi and Jagboro (2006) highlight that maintenance plays a vital role in prolonging the life of public infrastructure and reducing the need for costly repairs, especially in environments with limited resources and technological obsolescence. Their study underscores that sustained maintenance practices, characterized by consistent and proactive interventions, are essential for maximizing the value and utility of infrastructure assets in Nigeria.

Afolabi et al. (2018) and Olomolaiye et al. (2010) provide empirical evidence of a positive correlation between regular maintenance and improved performance of public utilities in Nigeria. Proactive maintenance strategies, including preventive and predictive maintenance, have been shown to reduce service disruptions, optimize resource allocation, and enhance operational efficiency. These studies also note that challenges such as inadequate funding, skills shortages, and outdated equipment often lead to frequent asset failures and suboptimal performance.

Odesola et al. (2019) further demonstrate that well-maintained infrastructure not only improves operational efficiency and cost-effectiveness but also enhances stakeholder satisfaction and public trust. The adoption of innovative technologies, specialized training programs, and routine inspection schedules are identified as opportunities to improve maintenance outcomes and support sustainable infrastructure management in Nigeria.

➢ *Recent Developments and Global Perspectives*

Globally, there is a growing recognition of the critical role that maintenance engineering plays in achieving sustainable asset management. International frameworks emphasize the integration of sustainability principles into asset management policies, including environmental protection, social responsibility, and economic efficiency. The adoption of Total Productive Maintenance (TPM) and other stakeholder-inclusive strategies is increasingly seen as essential for effective asset management across the asset lifecycle.

Asset management for sustainable service delivery now involves comprehensive processes such as asset condition and risk assessments, long-term financial planning, and the development of policies to ensure that asset data remains current. These advancements support the extension of asset lifecycles, reduce the need for emergency repairs, and promote the efficient use of resources.

In summary, the integration of maintenance engineering within sustainable asset management frameworks is fundamental for optimizing asset performance, reducing lifecycle costs, and achieving long-term sustainability goals—both globally and within the specific context of Nigeria.

➢ *Objective of the review*

The objective of this review is to systematically investigate and validate the key elements of organisational maintenance policies (OMPs) and their relevance to effective maintenance management, particularly within the Nigerian context. The review aims to assess whether maintenance policies and frameworks commonly utilised in developed countries are applicable and effective in developing countries like Nigeria. It seeks to identify critical factors that influence maintenance management of public buildings and infrastructure, with the goal of guiding policymakers, practitioners, and educators in formulating robust maintenance strategies that enhance asset longevity and sustainability. Additionally, the review intends to highlight gaps in current maintenance practices and propose recommendations for improving maintenance policy development, implementation, and integration with sustainable asset management objectives in Nigeria.

➢ *Clarification of the Review's Aims and Scope*

This review aims to critically examine the impact of maintenance engineering on sustainable asset management, with a specific focus on the Nigerian context. The primary goal is to understand how maintenance practices influence the longevity, performance, and sustainability of physical assets in Nigeria's industries and public infrastructure.

The scope of the review encompasses:

- *Maintenance Engineering Practices*

Exploring various maintenance strategies, including preventive, predictive, and corrective maintenance, and their effectiveness in asset management.

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- *Sustainable Asset Management*
  Investigating how sustainability principles—economic efficiency, environmental responsibility, and social equity—are integrated into maintenance and asset management processes.

- *Contextual Challenges*
  Identifying the unique challenges faced in Nigeria, such as funding constraints, skills shortages, policy gaps, and cultural factors affecting maintenance practices.

- *Comparative Analysis*
  Reviewing global best practices and frameworks in maintenance and sustainability to assess their applicability and adaptability to Nigeria's conditions.

By focusing on these areas, the review seeks to provide a comprehensive understanding of the current state of maintenance management in Nigeria, highlight critical gaps, and offer insights for developing more sustainable and effective maintenance policies and practices tailored to the Nigerian environment.

II. METHODOLOGY: OVERVIEW OF THE SYSTEMATIC REVIEW APPROACH

This study adopts a systematic review methodology to comprehensively analyze existing literature related to maintenance engineering and sustainable asset management, particularly focusing on the Nigerian context. The systematic review approach ensures a rigorous, transparent, and replicable process for identifying, selecting, and synthesizing relevant research findings.

➢ *Data Sourcing*

The review involved an exhaustive search of academic databases and electronic repositories to capture a wide range of relevant studies. Key databases included platforms such as Emerald Insight, ScienceDirect, SpringerLink, InformaWorld, and other scholarly sources. Additionally, relevant books, conference proceedings, and grey literature were considered to ensure a broad and inclusive data set.

➢ *Search Strategies*

A structured search strategy was developed using a combination of keywords and phrases related to maintenance engineering, asset management, sustainability, and Nigeria. Boolean operators (AND, OR) were used to refine the search and improve relevance. The search was limited to publications within a defined time frame to capture both foundational and recent developments in the field.

The search process was iterative, involving initial broad searches followed by more focused queries based on emerging themes and gaps identified in preliminary results. Reference lists of key articles were also screened to identify additional relevant studies.

➢ *Criteria for Study Selection*

Inclusion criteria for selecting studies were:

Empirical or theoretical research focused on maintenance management, performance measurement, or sustainability in asset management. Studies conducted within Nigeria or providing comparative insights relevant to the Nigerian context. Publications in peer-reviewed journals, reputable conferences, or authoritative reports. Availability of full-text articles in English.

➢ *Exclusion Criteria Included:*

- Studies unrelated to maintenance or asset management.
- Articles lacking methodological rigor or sufficient detail.
- Non-English publications or inaccessible full texts.

➢ *Data Extraction and Analysis*

Selected studies were systematically reviewed, and data were extracted according to predefined categories such as study objectives, methodologies, key findings, and identified challenges. Content analysis was employed to classify and synthesize findings, enabling identification of common themes, trends, and research gaps.

The process ensured that redundant or overlapping information was minimized, focusing on studies that contribute unique insights or robust evidence. Quantitative data, where available, were summarized descriptively to support thematic interpretations.

This methodological approach provides a comprehensive and balanced understanding of the state of maintenance engineering and sustainable asset management research, highlighting areas of strength and opportunities for future investigation.

III. LITERATURE REVIEW

➢ *Maintenance Engineering: Definitions and Concepts*

Maintenance engineering is a specialized field within engineering focused on the application of technical, managerial, and operational principles to ensure that physical assets—such as machinery, equipment, and infrastructure—are maintained in a condition that supports their intended function effectively, safely, and reliably. It encompasses the planning, execution, and control of maintenance activities aimed at minimizing downtime, extending asset life, and optimizing operational costs.

According to the European standard BS EN 13306 (2010), maintenance is defined as "the combination of all technical, administrative, and managerial actions during the life cycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" (Soesatijono, 2021). This definition highlights maintenance as a lifecycle activity, spanning both preventive and corrective actions.

Ben-Daya et al. (2016) categorize maintenance into two main classes: Corrective Maintenance (CM) and Preventive Maintenance (PM). Corrective maintenance is reactive,

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performed after equipment failure to restore functionality, whereas preventive maintenance is proactive, carried out before failure based on time intervals or condition monitoring. A subclass of PM, Condition-Based Maintenance (CBM), uses real-time monitoring and data analysis to predict failures and schedule maintenance optimally, a practice increasingly relevant in the context of Industry 4.0 and digitalization (SciELO, 2022).

Maintenance effectiveness, a key concept within maintenance engineering, is defined as the extent to which maintenance policies achieve their predefined objectives, such as minimizing downtime, reducing costs, and improving reliability (SciELO, 2022). It is studied from two perspectives: the organizational view—focusing on maintenance management, resource allocation, and human factors—and the operational view—centering on the performance and outcomes of maintenance actions (Ben-Daya et al., 2009; Kobbacy & Murthy, 2008).

Advanced maintenance strategies such as Total Productive Maintenance (TPM) and Reliability-Centered Maintenance (RCM) are designed to improve maintenance effectiveness. TPM involves all employees in maintenance activities to achieve zero breakdowns and losses, while RCM systematically determines maintenance requirements based on asset operating context and failure modes (Moubray, 1997; Ben-Daya, 2000). These approaches aim to optimize maintenance activities to enhance asset availability, reliability, and safety.

Recent developments in maintenance engineering emphasize the integration of predictive analytics, digital twins, and condition monitoring technologies to enable smarter maintenance decisions and improve asset performance (Soesatijono, 2021). This evolution reflects a shift from reactive to proactive and predictive maintenance paradigms, aligned with sustainability goals by reducing resource wastage and environmental impact.

➢ *Sustainable Asset Management: Definitions and Concepts*

Sustainable asset management refers to the strategic management of physical assets in a manner that balances economic performance, environmental protection, and social responsibility throughout the asset lifecycle. It integrates sustainability principles into asset planning, operation, maintenance, and disposal to ensure long-term value creation without compromising future needs.

Schröder and Baumgartner (2010) define sustainable plant asset management as an approach that considers environmental and social aspects alongside economic factors in asset operations and maintenance. Their lifecycle perspective emphasizes minimizing resource consumption, emissions, and waste while maintaining asset reliability and safety.

The International Infrastructure Management Manual (IIMM) describes sustainable asset management as the process of managing infrastructure assets to deliver agreed levels of service in the most cost-effective manner while minimizing environmental impacts and supporting community well-being (Asset Management BC, 2019). This involves comprehensive asset data management, risk assessment, and long-term financial planning.

Key components of sustainable asset management include:

- *Lifecycle Costing*

Evaluating the total cost of owning and operating assets over their lifespan, including acquisition, operation, maintenance, and disposal costs.

- *Risk Management*

Identifying and mitigating risks that could impact asset performance, safety, or sustainability.

- *Performance Measurement*

Using indicators such as asset availability, environmental emissions, and social impact to monitor and improve asset management practices.

- *Stakeholder Engagement*

Incorporating the needs and expectations of stakeholders, including communities, regulators, and customers, into asset decision-making.

The integration of maintenance engineering into sustainable asset management is critical, as maintenance activities directly influence asset reliability, operational efficiency, and environmental footprint. Effective maintenance reduces unplanned downtime, extends asset life, and minimizes resource consumption, thereby supporting sustainability objectives (Van Dongen, 2021).

➢ *Interrelationship Between Maintenance Engineering and Sustainable Asset Management*

Maintenance engineering and sustainable asset management are inherently linked. Maintenance ensures that assets perform reliably and efficiently, which is fundamental to achieving sustainability goals. Conversely, sustainability considerations influence maintenance strategies by prioritizing resource efficiency, waste reduction, and social responsibility.

Kobbacy and Murthy (2008) highlight that maintenance effectiveness is a key enabler of sustainable asset management, as it improves asset performance while controlling costs and environmental impacts. The shift towards condition-based and predictive maintenance exemplifies this integration by enabling timely interventions that prevent failures and reduce unnecessary maintenance activities.

Moreover, advanced maintenance management frameworks incorporate sustainability criteria into maintenance decision-making, balancing technical performance with environmental and social considerations (Ben-Daya et al., 2016). This holistic approach is essential for industries and infrastructure sectors aiming to align with global sustainability agendas and regulatory requirements.

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- *Relationship Between Maintenance and Sustainability*

Maintenance plays a critical role in achieving sustainability, particularly in the management of buildings, infrastructure, and industrial assets. Sustainability in this context refers to meeting present needs without compromising the ability of future generations to meet theirs, encompassing economic, environmental, and social dimensions. The relationship between maintenance and sustainability is increasingly recognized as essential for prolonging asset life, reducing resource consumption, and minimizing environmental impacts.

Saniuk et al. (2015) emphasize that proactive and well-planned maintenance significantly increases the lifespan of buildings and infrastructure. This reduces the frequency of replacements and prevents premature disposal of materials, thereby conserving natural resources and reducing waste. Proper maintenance also enhances the operational efficiency of buildings, leading to lower energy consumption and greenhouse gas emissions. Conversely, poor maintenance practices, such as deferred or reactive maintenance, can cause premature equipment failures, increased energy use, and higher costs, which negatively affect sustainability (Izobo-Martins, Ekhaese & Ayo-Vaughan, 2018).

Sherwin (2000) found that regular maintenance can reduce energy consumption in buildings by up to 40%, illustrating the direct environmental benefits of maintenance activities. Similarly, Othuman (2014) showed that proper maintenance enhances the environmental performance of green buildings, reinforcing the role of maintenance in achieving sustainability goals. Youhansen, Ahmed, and Laila (2021) further confirm that maintenance conserves natural resources, reduces waste, and minimizes environmental impacts while improving the efficiency and performance of infrastructure.

From an organizational perspective, sustainable maintenance practices (SMPs) have been shown to positively impact a company's economic, social, and environmental performance (Chiang et al., 2014; Liyanage et al., 2009). However, research on sustainable maintenance is still emerging, with many companies lacking a full understanding of its importance for achieving sustainable performance (Pires et al., 2016; Zhang et al., 2017). SMA (Sustainable Maintenance Activities) is defined as maintenance operations that balance social welfare, environmental protection, and financial considerations (Jasiulewicz-Kaczmarek, 2013a; 2013d). Studies confirm that adopting SMA leads to improvements across all sustainability dimensions, including economic development, environmental protection, and social welfare (Mahmood et al., 2015; Frank et al., 2016).

In the facility and manufacturing sectors, maintenance is a key strategy for achieving sustainability by maintaining product quality and reducing production costs (BenoitIung & Levrat, 2014). Integrating sustainability goals into traditional maintenance management through new technologies represents a creative approach to sustainability (Franciosi et al., 2020). Maintenance affects production volume, equipment availability, and final product quality, all of which influence sustainability outcomes (Sinaga et al., 2022).

Despite the recognized importance of maintenance for sustainability, there remains a lack of comprehensive frameworks to measure and manage maintenance impacts on sustainability in various industries (Hojjati, Jefferson & Metje, 2018). Systematic literature reviews highlight the need for better understanding and monitoring of maintenance processes to safeguard the economic, environmental, and social pillars of sustainability in industrial and infrastructure sectors.

In buildings, maintenance management practices directly influence sustainability by improving energy efficiency, reducing waste, and enhancing occupant health and safety (IEOM Society, 2021). However, inefficiencies in current maintenance management hinder the full realization of sustainability benefits. Research calls for the development of frameworks that integrate sustainability considerations into maintenance management, including detailed factors affecting maintenance and the impact of sustainable strategies on maintenance outcomes.

In summary, maintenance is a fundamental enabler of sustainability. Proactive, well-planned, and technologically supported maintenance practices extend asset life, reduce resource consumption, lower emissions, and enhance social welfare. The integration of sustainability principles into maintenance management is essential for achieving sustainable development goals across industries and infrastructure sectors.

- *Maintenance Culture and its Impact on Asset Longevity in Nigeria*

Maintenance culture refers to the collective attitudes, values, behaviors, and practices regarding the upkeep and repair of physical assets within a society or organization. In Nigeria, the maintenance culture has been widely recognized as poor and inadequate, significantly contributing to the rapid deterioration and premature failure of critical infrastructure and public assets. This weak maintenance culture has far-reaching consequences for asset longevity, economic development, and social welfare.

- *Current State of Maintenance Culture in Nigeria*

Nigeria's maintenance culture is characterized by neglect, insufficient funding, lack of skilled personnel, poor governance, and corruption. According to Nwachukwu (2024), Nigeria's development is significantly hindered by a poor maintenance culture that affects infrastructure and public facilities. Roads are riddled with potholes, public utilities experience frequent power outages, and public buildings such as schools and hospitals are often in disrepair. These issues stem from inadequate planning, weak governance, and mismanagement of resources, leading to rapid infrastructure decay.

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Research by Kashere Journal of Politics and International Relations (2023) highlights that successive Nigerian governments allocate budgets for maintenance but rarely execute these plans effectively. This results in the poor upkeep of public infrastructure, which drastically reduces the lifespan of assets. The study identifies poor leadership, corruption, insufficient maintenance workers, and lack of materials as major causes of this problem.

Furthermore, a study by Oyeniyi, Emmanuel, and Oladipupo (2023) on government-owned facilities in Ado Ekiti, Nigeria, found that despite significant investments in construction, buildings quickly fall into disrepair due to neglect and poor maintenance management. Reactive maintenance dominates, which only addresses problems after failure, leading to increased costs and shortened asset life.

➢ *Impact on Asset Longevity*

The direct consequence of Nigeria's poor maintenance culture is the accelerated deterioration of infrastructure and assets. Roads, bridges, public buildings, and industrial equipment deteriorate faster than their expected service life. For example, the World Bank reports that only about 15% of Nigeria's federal roads are paved and in good condition, with many requiring urgent repairs (Nwachukwu, 2024). Frequent power outages averaging 32.8 per month further illustrate the poor state of infrastructure maintenance.

This neglect leads to increased operational costs, frequent breakdowns, and premature replacement of assets, which wastes scarce financial resources. The poor maintenance of public healthcare facilities, with about 70% requiring major repairs, adversely affects service delivery and public health outcomes (Nwachukwu, 2024).

The economic implications are severe. Poorly maintained infrastructure raises the cost of doing business, discourages investment, and slows economic growth. Socially, it reduces quality of life by limiting access to safe roads, reliable power, and functional public services. The risk to human safety is also heightened by collapsing structures and unsafe roads.

➢ *Root Causes of Poor Maintenance Culture*

Several factors underpin Nigeria's poor maintenance culture:

- *Inadequate Funding*

Maintenance budgets are often insufficient or diverted, with priority given to new projects rather than upkeep (Kashere Journal, 2023).

- *Lack of Skilled Workforce*

There is a shortage of trained maintenance professionals, limiting the capacity to perform effective maintenance (Oyeniyi et al., 2023).

- *Weak Institutional Frameworks*

Absence of strong policies and enforcement agencies leads to neglect of maintenance responsibilities (Kashere Journal, 2023).

- *Corruption and Mismanagement*

Funds allocated for maintenance are sometimes misappropriated, undermining maintenance efforts (Nwachukwu, 2024).

- *Public Attitudes*

A general lack of awareness and appreciation for maintenance among citizens and organizations perpetuates neglect (Nwachukwu, 2024).

➢ *Efforts and Recommendations to Improve Maintenance Culture*

Improving Nigeria's maintenance culture requires a multi-faceted approach:

- *Policy Development*

Formulating and enforcing a national maintenance policy to institutionalize maintenance practices across all sectors (Kashere Journal, 2023).

- *Adequate Funding*

Ensuring that maintenance costs are included in project budgets and that funds are protected and properly managed (Oyeniyi et al., 2023).

- *Capacity Building*

Training and developing skilled maintenance personnel to enhance technical and managerial capabilities (Oyeniyi et al., 2023).

- *Community Engagement*

Promoting awareness and ownership of public assets among citizens to foster responsibility and care (Nwachukwu, 2024).

- *Preventive Maintenance*

Shifting from reactive to proactive maintenance strategies to prevent asset failures and extend service life (Nwachukwu, 2024).

- *Strengthening Governance*

Enhancing transparency and accountability to reduce corruption and improve maintenance management (Nwachukwu, 2024).

Therefore, the poor maintenance culture in Nigeria significantly shortens the lifespan of critical assets, undermining economic growth and social welfare. Addressing this challenge requires committed leadership, adequate resources, skilled manpower, and active community participation. By fostering a positive maintenance culture, Nigeria can preserve its infrastructure investments, reduce costs, and support sustainable development.

IV. CHALLENGES IN MAINTENANCE PRACTICES IN NIGERIA

Maintenance practices in Nigeria face significant challenges that undermine the effectiveness and sustainability of asset management across various sectors. These challenges primarily revolve around inadequate funding, shortage of

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skilled personnel, and weak policy frameworks. Together, these factors contribute to the poor upkeep of infrastructure and assets, leading to premature failure, increased costs, and reduced service delivery.

A. Funding Constraints

One of the most critical challenges in maintenance practices in Nigeria is inadequate funding. Maintenance activities are often underfunded or neglected altogether in favor of new construction projects. According to Ekpo and Ayeni (2025), maintenance in Nigeria tends to be reactive rather than proactive, largely due to insufficient budget allocations. The Federal Roads Maintenance Agency (FERMA) proposed a budget of N64.88 billion for road maintenance in 2025, which many experts argue is insufficient given the extensive deterioration of the road network (Daily Trust, 2025).

The lack of sustainable funding results in deferred maintenance, where repairs and upkeep are delayed until assets fail, increasing the cost of restoration and reducing asset lifespan. In the building sector, Oladipo and colleagues (2015) identified that poor maintenance funding leads to accelerated dilapidation of facilities, with defects such as peeling walls, foundation failures, and sagging beams becoming prevalent. This funding gap is compounded by poor financial management and corruption, which further limit the resources available for maintenance.

B. Shortage of Skilled Personnel and Technical Expertise

Nigeria faces a significant shortage of skilled maintenance technicians and engineers, which hampers effective maintenance delivery. The aviation sector, for example, struggles with a lack of qualified technicians to meet the growing demand for aircraft maintenance, repair, and overhaul (MRO) services (MarkWide Research, 2025). This shortage affects not only aviation but also construction, manufacturing, and public infrastructure maintenance.

The lack of vocational training centers and limited investment in skill development programs exacerbate this problem. Many maintenance activities are performed by untrained personnel, leading to substandard repairs and recurring asset failures. Efforts to address this gap include government initiatives to establish training centers and partnerships with international firms, but progress remains slow (MarkWide Research, 2025).

C. Policy and Regulatory Challenges

Weak policy frameworks and poor enforcement of maintenance regulations constitute another major challenge. Nigeria lacks a comprehensive national maintenance policy that mandates and guides maintenance activities across sectors. The absence of clear policies results in inconsistent maintenance practices and low prioritization of maintenance in organizational budgets and planning (Kashere Journal of Politics and International Relations, 2023).

Bureaucratic bottlenecks and regulatory inefficiencies further delay maintenance approvals and funding disbursements. Corruption and mismanagement also undermine regulatory compliance, with funds allocated for maintenance sometimes diverted or misused (Costarchem Nigeria, 2025). Additionally, there is a lack of standardized maintenance protocols and performance monitoring systems, which makes it difficult to assess maintenance effectiveness and hold responsible parties accountable.

D. Infrastructure and Logistic Constraints

Poor infrastructure and logistical challenges hinder timely and effective maintenance. Inadequate transportation networks and unreliable power supply complicate the delivery of maintenance materials and services, leading to delays and increased costs (Costarchem Nigeria, 2025). In the construction sector, the high cost of materials and scarcity of quality inputs also affect maintenance quality.

E. Cultural and Organizational Attitudes

A pervasive maintenance culture deficit exists in Nigeria, where maintenance is often seen as a low priority or an afterthought. Many organizations and government agencies adopt a reactive approach, addressing maintenance only after failures occur. This attitude leads to neglect and accelerated asset deterioration (Uma, Obidike & Ihezukwu, 2014). Public awareness about the importance of maintenance is generally low, and there is limited accountability for maintenance failures.

V. EXISTING MAINTENANCE FRAMEWORKS AND SUSTAINABILITY STRATEGIES: GLOBAL AND LOCAL PERSPECTIVES

- *Global Maintenance Frameworks and Sustainability Strategies*

Globally, maintenance frameworks are evolving rapidly to incorporate advanced technologies and sustainability principles, transforming maintenance from a reactive, cost-driven function into a proactive, strategic enabler of asset longevity and environmental stewardship.

A. Predictive and Condition-Based Maintenance (CBM)

Predictive maintenance, powered by Artificial Intelligence (AI), Machine Learning (ML), and Industrial Internet of Things (IIoT), is becoming the cornerstone of modern maintenance frameworks worldwide. Instead of relying on fixed schedules, predictive maintenance uses real-time data and analytics to forecast equipment failures before they occur, allowing maintenance teams to intervene proactively and minimize downtime (Snapfix, 2024; MicroMain, 2024). This approach not only improves asset reliability but also reduces unnecessary maintenance activities, conserving resources and energy.

Condition-Based Maintenance (CBM), a subset of predictive maintenance, monitors asset conditions continuously and triggers maintenance only when specific indicators show degradation. This strategy optimizes resource use and extends asset life, aligning closely with sustainability goals by reducing waste and emissions.

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B. Integration of Sustainability Principles

Sustainability has shifted from a peripheral concern to a core operational imperative in maintenance frameworks globally. Organizations are adopting circular economy practices such as repairing, refurbishing, and repurposing components to minimize waste and resource consumption (Snapfix, 2024). Carbon-neutral operations are pursued by leveraging low-emission tools, tracking carbon footprints, and integrating renewable energy sources with maintenance activities.

Smart energy management systems are increasingly incorporated into maintenance strategies to optimize energy use and reduce environmental impacts. These sustainability-focused maintenance practices extend asset lifespans and position organizations as leaders in responsible operations, delivering both cost savings and environmental benefits.

C. Unified Digital Ecosystems and Edge Computing

Modern maintenance frameworks emphasize seamless collaboration across departments, contractors, and suppliers through centralized digital platforms. These ecosystems consolidate maintenance data, communication, and workflows, enabling real-time oversight and resource optimization (Snapfix, 2024). Edge computing decentralizes data processing, allowing for localized analytics and faster decision-making even in low-connectivity environments, enhancing resilience and agility in maintenance operations.

D. Agile and Lean Maintenance Practices

Agility is key in contemporary maintenance frameworks. Lean methodologies and dynamic scheduling, supported by AI, allow maintenance operations to adapt swiftly to changing conditions and operational demands. Just-in-time inventory management and modular tools reduce waste and improve efficiency (Snapfix, 2024).

E. Computerized Maintenance Management Systems (CMMS)

CMMS platforms have evolved to automate routine tasks such as work orders, inventory management, and reporting. Integration with AI and IoT devices enables predictive analytics and comprehensive asset health monitoring, facilitating data-driven decision-making and continuous improvement (MicroMain, 2024; Mapcon, 2025).

VI. LOCAL MAINTENANCE FRAMEWORKS AND SUSTAINABILITY STRATEGIES IN NIGERIA

In Nigeria, maintenance frameworks and sustainability strategies are gradually evolving but face unique challenges due to infrastructural deficits, funding constraints, and limited technical capacity. Nevertheless, efforts are underway to align local practices with global trends.

A. Emerging Adoption of Predictive Maintenance

While preventive maintenance remains dominant in many Nigerian industries, there is increasing interest in predictive maintenance technologies, particularly in sectors such as oil and gas, manufacturing, and power generation. Some organizations are beginning to deploy sensor-based monitoring and data analytics to anticipate failures and optimize maintenance schedules, though adoption is still limited by cost and skills gaps.

B. Policy and Institutional Development

Nigeria is making strides toward formalizing maintenance practices through national policies and institutional frameworks. The Federal Ministry of Works and Housing and agencies like the Federal Roads Maintenance Agency (FERMA) are developing guidelines to improve maintenance planning and execution (Nwachukwu, 2024). However, enforcement and funding remain challenges.

C. Sustainability Integration Efforts

Sustainability considerations are increasingly incorporated into asset management in Nigeria, especially in public infrastructure projects supported by international development partners. Emphasis is placed on lifecycle costing, environmental impact assessments, and community engagement to ensure that maintenance activities support long-term economic and social goals.

D. Capacity Building and Training

Recognizing the skills shortage, Nigerian institutions and private sector players are investing in training programs to develop maintenance engineers and technicians proficient in modern maintenance technologies and sustainability principles. Partnerships with international organizations facilitate knowledge transfer and adoption of best practices.

E. Challenges and Opportunities

Despite progress, Nigerian maintenance frameworks still contend with funding shortages, inadequate infrastructure, and cultural barriers to proactive maintenance. However, the growing availability of digital tools, mobile maintenance applications, and cloud-based CMMS solutions offers opportunities to leapfrog traditional limitations and enhance maintenance effectiveness sustainably.

VII. GAPS IN CURRENT RESEARCH AND PRACTICE IN NIGERIAN MAINTENANCE MANAGEMENT

Maintenance management in Nigeria is a critical area that influences the longevity and performance of infrastructure and assets. However, both research and practical implementation in this field exhibit significant gaps that hinder the development of effective maintenance systems aligned with global standards and sustainability goals. These gaps span issues of policy, professional capacity, technology adoption, standardization, and funding.

A. Lack of Standardized Maintenance Policies and Frameworks

A key research gap identified is the absence of comprehensive and context-specific maintenance policies tailored to Nigerian conditions. While organizational maintenance policies (OMPs) are well studied and implemented in developed countries, their applicability and adaptation to Nigeria’s unique socio-economic and

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institutional environment remain underexplored (Emerald Insight, 2022). Research by Duffuaa et al. (1999) and recent studies confirm that many Nigerian public buildings and infrastructure lack adequate maintenance policy frameworks, leading to inconsistent and reactive maintenance practices.

The Nigerian built environment suffers from a fragmented approach to maintenance policy, with limited coordination among stakeholders such as government agencies, contractors, and facility managers. This fragmentation results in poor prioritization, inadequate risk management, and lack of clear maintenance procedures, which are essential elements identified by experts for effective maintenance management (Emerald Insight, 2022).

B. Scarcity of Skilled Professionals and Training Programs

The Nigerian facility management and maintenance sector faces a critical shortage of skilled professionals. Novatia Consulting (2024) highlights a scarcity of trained facility managers and technicians with expertise in engineering disciplines, HVAC, electrical systems, and project management. This skills gap limits the operational effectiveness of maintenance services and constrains the adoption of modern maintenance strategies.

Furthermore, there is a deficiency in structured education and training programs focused on maintenance management and sustainability. This gap affects both the quantity and quality of available professionals, impeding the sector's ability to meet increasing demands driven by rapid urbanization and infrastructure expansion (Novatia Consulting, 2024).

C. Limited Adoption of Modern Technologies and Digital Tools

Despite global advances in maintenance technologies such as IoT, Computer-Aided Facility Management (CAFM) systems, and predictive analytics, Nigerian maintenance management practices largely remain traditional and manual. The slow digital transformation is partly due to limited awareness, high costs, and lack of technical capacity to implement and maintain such systems (Novatia Consulting, 2024; MarkWide Research, 2025).

Research into the barriers to technology adoption, such as Building Information Modeling (BIM) in Nigerian universities, reveals challenges including inadequate infrastructure, resistance to change, and insufficient training (IRE Journals, 2025). This technological lag restricts the ability to perform condition-based and predictive maintenance, which are crucial for sustainability and cost-effectiveness.

D. Funding and Financial Constraints

Financial limitations are a persistent challenge affecting maintenance research and practice in Nigeria. Budget allocations for maintenance are often insufficient, irregular, or diverted, leading to deferred maintenance and asset deterioration (Novatia Consulting, 2024). Research rarely addresses sustainable financing models or innovative funding mechanisms to support long-term maintenance programs.

Moreover, the economic environment characterized by inflation, currency volatility, and competing development priorities further constrains maintenance investments. This financial instability hampers the implementation of strategic maintenance plans and acquisition of necessary materials and technologies.

E. Inadequate Research on Maintenance Performance Metrics and Sustainability Integration

There is a notable lack of empirical studies focusing on maintenance performance measurement tailored to Nigerian industries and public infrastructure. While global literature emphasizes performance indicators such as mean time to repair, asset availability, and lifecycle costing, Nigerian research seldom develops or validates such metrics within local contexts (Emerald Insight, 2022).

Additionally, the integration of sustainability principles into maintenance management is under-researched. Although sustainability is gaining attention globally, Nigerian maintenance practices rarely incorporate environmental and social considerations systematically. This gap limits the potential for maintenance to contribute to sustainable development goals.

F. Fragmented Industry Practices and Lack of Professional Standardization

Facility management and maintenance services in Nigeria operate within a fragmented industry structure, with varying standards and practices. Novatia Consulting (2024) notes the absence of unified regulatory frameworks and professional accreditation systems, leading to inconsistent service quality and inefficiencies.

The lack of standardization affects outsourcing arrangements, contract management, and quality assurance, undermining trust and performance in maintenance operations. Research into establishing industry-wide standards and best practices remains limited.

Hence, the gaps in Nigerian maintenance management research and practice highlight the urgent need for targeted interventions. Developing robust, locally relevant maintenance policies, investing in human capital, embracing digital transformation, securing sustainable funding, and standardizing industry practices are critical steps. Addressing these gaps will enhance asset longevity, operational efficiency, and sustainability, supporting Nigeria's broader development objectives.

VIII. LESSONS LEARNED AND RECOMMENDATIONS: SUMMARY OF KEY INSIGHTS, LESSONS LEARNED, AND RECOMMENDATIONS FOR BEST PRACTICES ON THE IMPACT OF MAINTENANCE ENGINEERING ON SUSTAINABLE ASSET MANAGEMENT

The review highlights that effective maintenance engineering is crucial for sustainable asset management, as it directly influences asset longevity, operational efficiency,

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and environmental performance. A strong maintenance culture, supported by adequate funding, skilled personnel, and robust policies, is essential to prevent premature asset failure and reduce lifecycle costs. It is evident that reactive maintenance practices prevalent in Nigeria lead to increased downtime and higher expenses, underscoring the need to shift towards preventive and predictive maintenance strategies.

Lessons learned from global best practices emphasize the integration of digital technologies such as IoT, predictive analytics, and computerized maintenance management systems to enhance maintenance effectiveness and sustainability outcomes. Additionally, stakeholder engagement and continuous capacity building are vital for fostering ownership and improving maintenance execution.

Based on these insights, it is recommended that Nigerian organizations and policymakers prioritize the development and enforcement of comprehensive maintenance policies that incorporate sustainability principles. Investment in training and skill development programs should be increased to build a competent maintenance workforce. Adoption of modern maintenance technologies and data-driven approaches will improve decision-making and resource allocation. Furthermore, establishing dedicated maintenance funding streams and promoting a proactive maintenance culture will ensure assets are preserved and utilized optimally. Finally, collaboration among government, industry, and academia is essential to develop context-specific frameworks and drive continuous improvement in maintenance management practices.

IX. FUTURE DIRECTIONS

Looking ahead, maintenance engineering and sustainable asset management in Nigeria are poised to benefit from several emerging trends and strategic shifts. First, the integration of renewable energy systems such as solar panels, microgrids, and hybrid energy solutions into building and infrastructure maintenance will become increasingly important. These technologies will reduce reliance on fossil fuels and support Nigeria's broader sustainability goals.

Advanced energy storage technologies, including lithium-ion and solid-state batteries, are expected to enhance energy resilience and reliability, particularly in regions prone to power outages. The adoption of smart grids and AI-driven energy management systems will further optimize energy use and maintenance scheduling, contributing to greener and more efficient asset management.

Water conservation will also become a critical focus, with smart plumbing solutions, sensor-based fixtures, and greywater recycling systems gaining traction to address water scarcity challenges. Incorporating rainwater harvesting and water-efficient HVAC systems into maintenance strategies will promote resource conservation and environmental compliance.

Digitization and Industry 4.0 technologies will continue to transform maintenance practices. The use of IoT sensors, real-time data analytics, and predictive maintenance tools will enable more proactive and precise maintenance interventions. This smart engineering approach will improve asset availability, reduce downtime, and lower operational costs.

Capacity building remains essential, with increased emphasis on training programs to equip maintenance professionals with skills in emerging technologies and sustainability practices. Collaboration between government, industry, and educational institutions will be vital to develop tailored curricula and certification programs.

Finally, policy reforms aimed at establishing comprehensive maintenance frameworks, enforcing standards, and securing sustainable funding will be critical to institutionalizing best practices. Encouraging public-private partnerships and leveraging international support can accelerate the adoption of innovative maintenance solutions.

Together, these future directions offer a pathway for Nigeria to enhance its maintenance culture, improve asset longevity, and achieve sustainable development objectives through smarter, greener, and more resilient maintenance management.

X. CONCLUSION

This review has demonstrated that maintenance engineering plays a pivotal role in achieving sustainable asset management, particularly within the Nigerian context where infrastructure challenges and resource constraints are prevalent. Effective maintenance practices directly influence asset longevity, operational efficiency, and environmental sustainability. However, Nigeria faces significant challenges including inadequate funding, shortage of skilled personnel, weak policy frameworks, and a pervasive reactive maintenance culture that undermines asset performance and accelerates deterioration.

Globally, maintenance frameworks are evolving with the integration of advanced technologies and sustainability principles, offering valuable lessons for Nigeria. The adoption of predictive maintenance, digital tools, and sustainable strategies can significantly enhance maintenance effectiveness and support long-term asset sustainability. Locally, efforts to develop maintenance policies, build capacity, and incorporate sustainability considerations are underway but require strengthening and wider implementation.

The gaps identified in research and practice highlight the need for comprehensive, context-specific maintenance policies, investment in human capital, technological adoption, and sustainable financing models. Addressing these gaps will enable Nigeria to transition from reactive to proactive maintenance, reduce lifecycle costs, and improve service delivery.

Future directions suggest embracing renewable energy integration, smart technologies, water conservation, and Industry 4.0 innovations to modernize maintenance management. Collaborative efforts among government, industry, and academia are essential to institutionalize best practices and foster a maintenance culture that supports sustainable development.

In summary, advancing maintenance engineering in Nigeria through strategic reforms, capacity building, and technology adoption is critical for enhancing asset longevity and achieving sustainable asset management goals that contribute to national economic growth and social well-being.

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