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Exploring the Role of Digital Technologies in Improving Marine Engineering Management Efficiency. A Case of Dar es Salaam Port

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Abstract: *Marine engineering management has increasingly adopted digital technologies to improve operational efficiency, maintenance planning, and engineering decision-making in modern ports. Despite ongoing digital transformation initiatives at Dar es Salaam Port, limited empirical evidence exists on stakeholders' experiences with these technologies and their perceived influence on marine engineering management efficiency. This article explored the role of digital technologies in improving marine engineering management efficiency at Dar es Salaam Port by examining stakeholders' experiences with digital technologies and their perceptions of their influence on management efficiency. The study employed a qualitative case study design involving 25 purposively selected participants, including marine engineers, maintenance engineers, ICT officers, port operations managers, technical managers, mechanical engineers, Tanzania Ports Authority officials, and Tanzania Shipping Agencies Corporation representatives. Data were collected through semi-structured interviews and analyzed using thematic analysis. The findings revealed that Internet of Things (IoT) sensors were the most widely used digital technology, while artificial intelligence and Computerized Maintenance Management Systems (CMMS) were moderately utilized, and blockchain technology remained minimally adopted. Stakeholders reported improvements in equipment monitoring, maintenance planning, operational performance, engineering decision-making, and resource utilization, although challenges related to limited system integration, inadequate digital infrastructure, insufficient technical capacity, and continued reliance on conventional engineering practices persisted. The findings demonstrated that digital technologies strengthened marine engineering management efficiency at Dar es Salaam Port, while highlighting the need for greater technological integration and institutional capacity to maximize their benefits. These findings contribute to the growing body of knowledge on digital transformation in maritime engineering management and provide empirical evidence to support future digitalization initiatives within Tanzanian ports.*

Keywords— Digital Technologies, Marine Engineering Management, Operational Efficiency, Digital Transformation, Port Efficiency, Maintenance Management, Internet of Things (Iot), Artificial Intelligence

1. INTRODUCTION

The rapid advancement of digital technologies has transformed various sectors, including maritime operations, by enhancing efficiency, safety, and sustainability. This study explores the role of digital technologies such as IoT, AI, automation, digital twins, and data analytics in improving marine engineering management efficiency at Dar es Salaam Port. As Tanzania's primary seaport and a critical gateway for East African trade, Dar es Salaam Port serves as a strategic case study to examine how digital adoption can address operational bottlenecks and elevate overall port performance.

Dar es Salaam Port serves as a crucial maritime gateway on the Indian Ocean, facilitating essential trade for Tanzania and several landlocked neighbors, including Zambia, Malawi, Burundi, Rwanda, and the Democratic Republic of Congo [1]. As a fundamental pillar of regional logistics and economic growth, the port's functionality directly influences the broader East African trade ecosystem. However, traditional operational models persist, characterized by manual management processes and significant systemic hurdles such as cargo congestion and equipment maintenance inefficiencies [2]). These legacy practices often result in substantial delays, elevated operational expenditure, and suboptimal resource allocation, highlighting the urgent need for structural modernization to maintain competitiveness in the global maritime market [3].

The efficacy of a port is inextricably linked to its marine engineering management, which oversees the operation and optimization of critical infrastructure, ranging from berths and cranes to complex dredging equipment and navigation systems [4]. This management function is vital for maintaining high levels of operational reliability, ensuring safety, and preventing costly service interruptions. When engineering assets are managed through reactive or inefficient methodologies, the risk of unforeseen equipment failure rises significantly, leading to decreased productivity and higher long-term maintenance costs [5, 6]. Consequently, a robust engineering management framework is essential for sustaining the seamless flow of maritime activities and ensuring port infrastructure remains resilient under high-capacity demands.

Global maritime leaders have increasingly transitioned toward digital transformation to address the complexities of modern port engineering. By integrating advanced technological solutions such as the Internet of Things (IoT) for predictive maintenance, digital twins, and Artificial Intelligence (AI) for operational analytics, ports have achieved marked improvements in asset monitoring and decision-making capabilities [7]. Furthermore, the implementation of Computerized Maintenance Management

Systems (CMMS) and blockchain technology has proven effective in enhancing supply chain transparency and ensuring environmental compliance [8]. These innovations collectively shift the focus from reactive repair strategies to proactive, data-driven engineering practices, which significantly elevate the overall safety and efficiency standards of international port operations.

Within the Tanzanian maritime sector, the Tanzania Ports Authority (TPA) has spearheaded various modernization projects in collaboration with international stakeholders to enhance operational infrastructure [1]. While these initiatives signify a foundational step toward digital maturity, the adoption of advanced engineering technologies remains fragmented and inconsistent across the port's diverse functions. Despite the acknowledged benefits of digitalization, there is a clear disconnect between the current manual-centric engineering practices at the Dar es Salaam Port and the sophisticated, technology-integrated standards adopted by leading global ports [2].

Figure 1, maps the transition of the marine engineering management process from legacy, reactive practices to an integrated digital ecosystem and it begins by tracking core technologies (such as IoT sensors, AI processing, and cloud frameworks) as they feed into real-time condition monitoring and machine learning pipelines. By automatically processing engine parameters and anomaly data, the workflow optimizes inventory, enables predictive maintenance, and streamlines repairs. The framework ultimately yields improved management performance, characterized by higher vessel availability, reduced mechanical downtime, lower operational costs, and elevated port sustainability.

Current literature and institutional reports indicate that while the Dar es Salaam Port has initiated several digitalization projects, these efforts remain largely disconnected from the specialized domain of marine engineering management. There is a lack of empirical research examining the specific impact of integrating digital technologies such as predictive maintenance tools and AI-driven analytics on the efficiency of marine engineering operations within the context of Tanzanian port infrastructure. Consequently, a significant research gap exists regarding how the comprehensive implementation of these digital tools can bridge the disparity between existing local engineering practices and internationally recognized best practices to optimize oprational reliability.

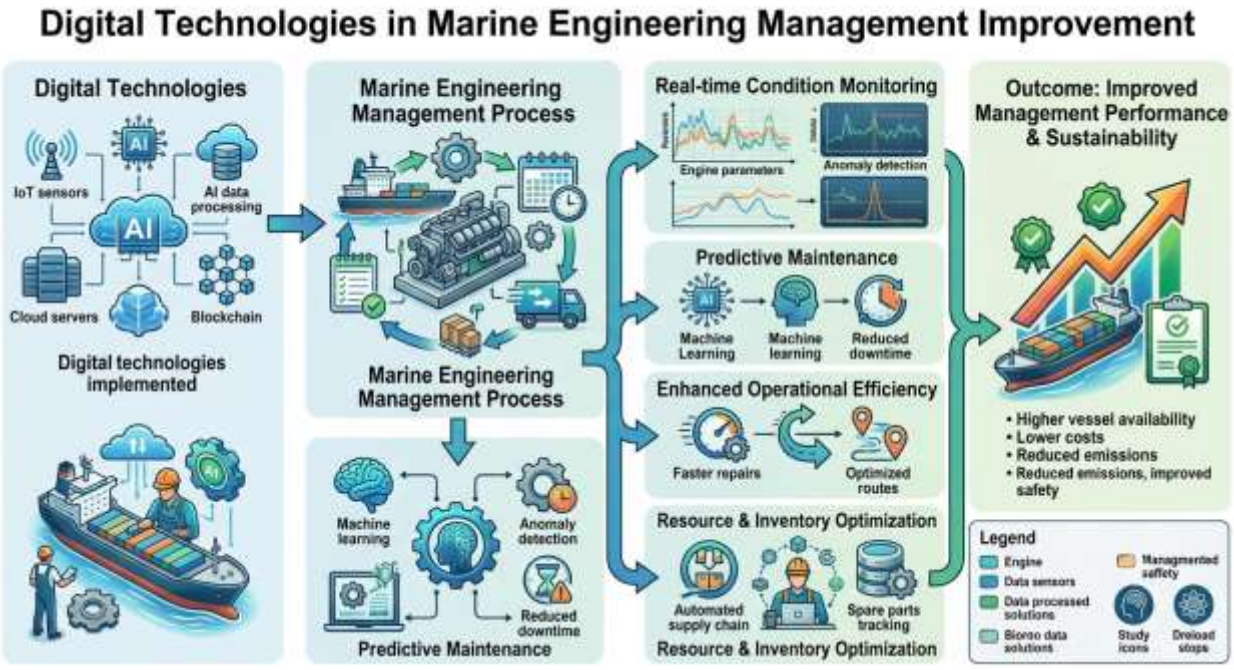

Figure 1: Showing the digital technologies in improving the marine engineering management

Despite being a strategic gateway for Tanzania and several landlocked neighboring countries, Dar es Salaam Port continued to face persistent challenges related to congestion, manual processes, equipment maintenance inefficiencies, and limited real-time monitoring, which undermined marine engineering management efficiency. While global ports had demonstrated that digital technologies such as IoT-based predictive maintenance, real-time asset monitoring, and automated management systems significantly improved operational reliability and reduced maintenance costs, the Tanzania Ports Authority had only partially integrated such systems into its engineering functions. As a result, there was

limited understanding of how digital technologies were actually used within marine engineering management at the port and how they influenced efficiency from the viewpoint of those directly involved. The absence of in-depth qualitative insights into stakeholders' experiences and perceptions made it difficult to assess the true role of digitalization in improving engineering operations and to identify contextual barriers and opportunities for aligning with international smart port standards. It was this gap that the present study sought to address.

This study aimed to explore the role of digital technologies in improving marine engineering management efficiency at Dar es Salaam Port. Specifically, the study sought to explore stakeholders' experiences regarding the use of digital technologies in marine engineering management at the port, and to examine stakeholders' perceptions of how these digital technologies influence marine engineering management efficiency.

The study contributed to the growing body of knowledge on digital transformation in the maritime sector by providing qualitative evidence on the role of digital technologies in improving marine engineering management efficiency at Dar es Salaam Port. It generated empirical insights into stakeholders' experiences regarding the use of digital technologies and their perceptions of how these technologies influenced operational performance, decision-making, and resource optimization within marine engineering management. The findings also highlighted the opportunities and challenges associated with the adoption of digital technologies in a developing port context, thereby extending the existing literature on digitalization in maritime engineering. In addition, the study provides practical evidence that can inform policymakers, the Tanzania Ports Authority, and port managers in designing strategies to strengthen digital transformation and improve the efficiency of marine engineering management.

2. RELATED STUDIES

2.1 Stakeholders' experiences regarding the use of digital technologies

Studies conducted in Europe and North America show that stakeholders have experienced substantial improvements in marine engineering management following the adoption of digital technologies. Marine engineers and port managers reported that technologies such as Computerized Maintenance Management Systems (CMMS), Internet of Things (IoT), artificial intelligence, and digital twins enhanced predictive maintenance, improved asset monitoring, and supported timely engineering decision-making [9]. Stakeholders also indicated that digital technologies strengthened coordination among engineering teams, reduced equipment downtime, and improved the overall reliability of port operations [10, 11].

In Asia, stakeholders in major ports have reported positive experiences with the adoption of digital technologies in engineering management. They observed that IoT, artificial intelligence, blockchain, and automated monitoring systems improved maintenance planning, facilitated early fault detection, and enhanced engineering communication [12]. Stakeholders further perceived that digital technologies increased operational efficiency and supported better engineering decision-making, although they emphasized the importance of staff training and organizational readiness for successful implementation [13].

African studies suggest that stakeholders have experienced gradual improvements in engineering management through digital technologies, although implementation remains uneven. Port engineers and managers reported that digital systems improved maintenance coordination and engineering information management, but their effectiveness was constrained by inadequate technological infrastructure, limited technical expertise, and financial constraints [14]. Stakeholders also highlighted that continuous investment in digital infrastructure and workforce capacity is essential for realizing the full benefits of digital transformation in port engineering operations [15].

In Tanzania, digital transformation within ports has mainly focused on cargo handling and operational management, with limited attention given to marine engineering management. Existing studies indicate that stakeholders have experienced improvements in information sharing and operational coordination through digital systems, but many engineering functions continue to rely on conventional maintenance practices [16, 17]. Consequently, stakeholders' experiences regarding the use of digital technologies in marine engineering management remain inadequately documented within the Tanzanian maritime sector [2].

The reviewed literature demonstrates that stakeholders in Europe, America, Asia, and parts of Africa have reported positive experiences regarding the use of digital technologies in engineering management. However, in Tanzania, existing studies have largely emphasized port operations, logistics, and cargo management, while little empirical attention has been given to stakeholders' experiences regarding the use of digital technologies in marine engineering management. This study addressed this gap by exploring stakeholders' experiences regarding the use of digital technologies in marine engineering management at Dar es Salaam Port.

2.2 Perceived influence of digital technologies on management efficiency

Studies conducted in Europe and North America have shown that digital technologies have positively influenced management efficiency in marine engineering and port operations. The adoption of technologies such as the Internet of Things (IoT), artificial intelligence, digital twins, and predictive maintenance systems has improved maintenance planning, reduced equipment downtime, and enhanced operational decision-making [18]. Furthermore,

digital technologies have enabled engineering managers to optimize resource allocation, improve asset reliability, and increase overall operational efficiency within ports [19].

In Asia, digital technologies are widely perceived as improving the efficiency of marine engineering management through automation and intelligent maintenance systems. The integration of big data analytics and smart engineering technologies has strengthened maintenance coordination, accelerated fault detection, and improved engineering planning in major ports [20]. These technologies have also supported timely and evidence-based decision-making, contributing to higher engineering performance and improved utilization of engineering resources [21].

Across Africa, stakeholders perceive digital technologies as valuable tools for improving management efficiency within port operations. The use of digital systems has enhanced equipment monitoring, maintenance coordination, and engineering service delivery in several ports [22]. However, the perceived benefits of digital technologies have been limited by inadequate digital infrastructure, insufficient technical expertise, and financial constraints that continue to affect their effective implementation [23].

In Tanzania, digital technologies are increasingly perceived as having the potential to improve management efficiency by enhancing operational coordination, maintenance planning, and information sharing. Although digital systems have contributed to improvements in some port operations, their application within marine engineering management remains relatively limited [24, 25]. Existing evidence also suggests that challenges related to technical capacity, system integration, and digital infrastructure continue to influence the effectiveness of digital technologies in improving engineering management efficiency [2].

Although global studies highlight positive stakeholder perceptions of digital technologies in enhancing management efficiency, there is insufficient empirical evidence capturing how Tanzanian stakeholders specifically perceive the influence of these technologies on marine engineering management efficiency at Dar es Salaam Port.

3. METHODOLOGY

The study adopted a qualitative research approach to explore stakeholders' experiences and perceptions regarding the role of digital technologies in improving marine engineering management efficiency at Dar es Salaam Port. The approach was appropriate because it enabled the researcher to obtain in-depth information about participants' views and experiences within the port environment [26]. A case study research design was employed to examine digital technology practices within the real-life context of Dar es Salaam Port [27]. The study involved a sample size of 25 participants selected through purposive sampling based on their knowledge and direct involvement in marine engineering management and digital technology use. The participants included marine engineers, maintenance engineers, port operations managers, ICT officers, marine technical officers, maintenance supervisors, and Tanzania Ports Authority officials responsible for engineering operations and digital systems. The sample size was considered adequate because qualitative research emphasizes depth of understanding and the selection of information-rich participants rather than statistical representation [28]. It was further justified by the achievement of data saturation, where additional interviews provided no new significant information [29]. Data were collected through semi-structured interviews and analyzed using thematic analysis to identify key patterns and themes related to the study objectives [30]. Ethical principles, including informed consent, confidentiality, anonymity, and voluntary participation, were maintained throughout the study [31].

4. RESULTS AND DISCUSSION

This section presents the findings of the study and discusses them in relation to existing literature on digital technologies and marine engineering management efficiency. The results are organized according to the study objectives, focusing on stakeholders' experiences regarding the use of digital technologies and their perceptions of how these technologies influence marine engineering management efficiency at Dar es Salaam Port. The discussion highlights key themes emerging from participants' responses and compares the findings with previous studies to provide a deeper understanding of digital transformation within port engineering operations.

4.1 Stakeholders' experiences regarding the use of digital technologies

This study explored stakeholders' experiences regarding the use of digital technologies in marine engineering management at Dar es Salaam Port. Specifically, it examined the types and extent of digital technologies adopted at the port, as well as stakeholders' practical experiences in using these technologies in their daily marine engineering operations.

4.1.1 Types and extent of digital technologies in use

The findings revealed that stakeholders experienced varying levels of adoption of digital technologies in marine engineering management at Dar es Salaam Port. Among the technologies identified, Internet of Things (IoT) sensors were the most widely used, as reported by 8 of the 25 participants. Respondents as presented in Figure 2, explained that IoT sensors had been installed on selected engineering equipment to continuously monitor operating conditions such as temperature, vibration, pressure, and machine performance. The technology enabled engineering personnel to detect potential equipment faults before they developed into major failures, allowing maintenance activities to be planned proactively rather than reactively. Participants further indicated that the use of IoT sensors had improved equipment monitoring, reduced unnecessary downtime, and enhanced the reliability of engineering operations. Nevertheless, they acknowledged that IoT implementation remained limited to

critical engineering assets, while many machines continued to rely on routine manual inspections due to limited technological coverage.

One senior marine engineer explained:

"…the introduction of IoT sensors has significantly improved the way we supervise engineering equipment. Previously, we depended entirely on scheduled inspections, but now some machines automatically alert us whenever there are abnormal changes in vibration, pressure, or temperature. This allows us to respond before a breakdown occurs and helps us reduce unnecessary maintenance delays. However, the technology has only been installed on a limited number of critical machines, meaning that a considerable portion of our engineering operations still depends on conventional monitoring methods…"

Another maintenance engineer added:

"…digital monitoring has made our work easier because we receive equipment performance information in real time instead of waiting until faults become visible during inspections. We are now able to organize maintenance more effectively and avoid some emergency repairs. However, the engineering department still requires additional investment so that similar technologies can be extended to other equipment throughout the port..."

The experiences shared by participants suggested that IoT technologies had begun transforming engineering maintenance practices by enabling continuous equipment monitoring and supporting preventive maintenance. Similar findings were reported in studies conducted in Europe and North America, where digital technologies enhanced predictive maintenance, improved asset monitoring, and strengthened engineering decision-making processes [9]. Comparable evidence also showed that digital technologies improved equipment reliability, minimized operational disruptions, and strengthened coordination among engineering personnel responsible for maintenance planning [10, 11]. While these international studies described comprehensive implementation of IoT technologies across engineering systems, the present findings indicated that adoption at Dar es Salaam Port remained partial, suggesting that digital transformation was still progressing within the port's marine engineering environment.

The findings further showed that artificial intelligence (AI) analytics was moderately used, with 7 participants indicating that AI-supported systems assisted engineering personnel in analyzing maintenance records, evaluating equipment performance, and identifying maintenance priorities. Participants explained that AI had improved the speed of engineering analysis and supported maintenance planning by organizing large volumes of engineering data. However, they also emphasized that many engineering decisions continued to rely on professional judgment because digital records remained incomplete and AI systems had not yet been fully integrated into all engineering processes.

One ICT officer explained:

"…artificial intelligence has started supporting our engineering activities by analyzing equipment performance records and identifying maintenance priorities much faster than manual methods. It helps us recognize patterns that may not be immediately visible to engineers. Nevertheless, we still depend heavily on engineers' experience because many maintenance records have not yet been fully digitized, limiting the amount of information available for AI analysis..."

Similarly, an engineering manager stated:

"…AI provides valuable recommendations for maintenance planning, but it cannot replace the practical knowledge of experienced engineers. Most of our important engineering decisions still combine digital analysis with professional judgment because the technology has not yet reached every section of the engineering department…"

These findings suggested that stakeholders viewed AI as an important complementary tool rather than a replacement for engineering expertise. Similar observations were reported in Asian ports, where artificial intelligence improved maintenance planning, engineering communication, and operational efficiency through automated analysis of engineering information [12]. Comparable studies also found that the successful application of AI depended on organizational readiness, digital infrastructure, and continuous staff training to ensure effective utilization of analytical systems [13]. The findings therefore demonstrated that Dar es Salaam Port had begun integrating AI into engineering management, although further digital maturity would be required before its full benefits could be realized.

The study also established that Computerized Maintenance Management Systems (CMMS) were occasionally used, as reported by 6 participants. Respondents explained that CMMS supported maintenance scheduling, work order management, equipment history documentation, and maintenance record keeping. They appreciated the ability of the system to organize engineering information and improve maintenance planning. However, participants reported that CMMS utilization remained inconsistent because some engineering units still relied on paper-based maintenance records and manual reporting systems, reducing opportunities for comprehensive digital coordination.

One maintenance supervisor explained:

"….the computerized maintenance management system has improved our ability to schedule maintenance activities and monitor completed work. We can retrieve equipment history much faster than before, which helps us make better maintenance decisions. However, not every engineering section consistently updates the system, meaning that some important maintenance records are still stored manually, making coordination more difficult..."

Another participant commented:

"…CMMS has simplified maintenance administration, but it is not yet fully integrated across the engineering department. Some maintenance teams continue using traditional

documentation methods, creating information gaps that reduce the overall effectiveness of the system..."

The findings indicated that stakeholders perceived CMMS as a useful engineering management tool despite its incomplete implementation. Similar experiences were reported in African ports, where digital maintenance systems strengthened maintenance coordination and engineering information management but continued to face implementation challenges associated with inadequate infrastructure and financial limitations [14]. Other studies similarly reported that limited technological investment and shortages of specialized technical personnel constrained the widespread adoption of digital engineering management systems across many African maritime organizations [15]. These findings suggested that Dar es Salaam Port faced challenges comparable to those experienced by other developing ports undergoing digital transformation.

Finally, the findings revealed that blockchain technology was rarely used, with only 4 participants reporting its application within marine engineering management. Most respondents explained that blockchain technologies remained largely associated with cargo documentation, customs processing, and logistics management rather than engineering maintenance. Consequently, stakeholders perceived blockchain as having considerable future potential but acknowledged that its practical application in engineering asset management and maintenance activities remained very limited.

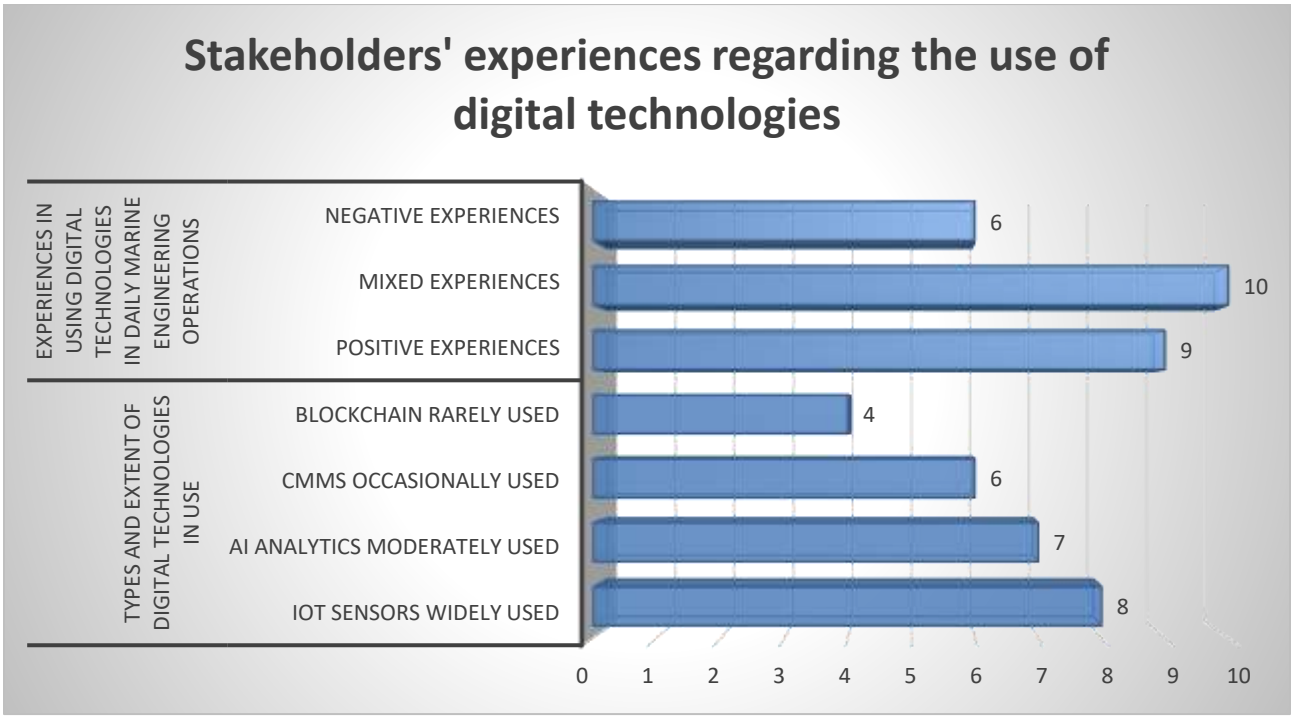

Figure 2: Showing the stakeholders' experiences regarding the use of digital technologies

One senior ICT specialist explained:

"…blockchain has received considerable attention in relation to cargo documentation and logistics management, but very little of its potential has been applied within marine engineering. Most engineering maintenance records are still handled through conventional systems, although blockchain could eventually improve transparency, equipment traceability, and maintenance documentation if properly implemented…"

The limited use of blockchain observed in the present study differed from experiences reported in Europe and North America, where blockchain technologies had increasingly supported engineering information management, asset traceability, and secure maintenance documentation [10]. Similar progress had also been reported in Asian ports, where blockchain formed part of broader smart port initiatives integrating engineering, logistics, and supply chain management systems [12]. However, the findings were consistent with studies conducted in Tanzania, which showed that digital transformation had primarily concentrated on cargo operations and port logistics while advanced digital technologies remained minimally applied within marine engineering management [16, 17]. These findings therefore demonstrated that although Dar es Salaam Port had begun adopting various digital technologies, the extent of utilization

differed considerably across technologies, with IoT sensors receiving the greatest attention while blockchain remained at a very early stage of implementation.

The findings demonstrated that the adoption of digital technologies in marine engineering management at Dar es Salaam Port was progressing, although the extent of implementation varied across different technologies. IoT sensors emerged as the most widely utilized technology due to their contribution to equipment monitoring and preventive maintenance, while artificial intelligence and CMMS were moderately integrated into engineering operations. Blockchain technology remained the least utilized, reflecting its early stage of adoption within marine engineering management. These findings suggest that although stakeholders recognized the value of digital technologies in enhancing engineering operations, greater investment in digital infrastructure, system integration, and technical capacity would be necessary to achieve comprehensive digital transformation and maximize management efficiency within the port.

4.1.2 Experiences in using digital technologies in daily marine engineering operations.

The findings as per figure 2, indicated that stakeholders reported varied experiences in using digital technologies in their daily marine engineering operations at Dar es Salaam Port. The largest proportion of participants, 10 out of 25 (40.0%), described having mixed experiences, suggesting that while digital technologies had improved certain engineering functions, challenges remained in achieving their full potential. Meanwhile, 9 participants (36.0%) reported positive experiences, explaining that digital technologies had enhanced equipment monitoring, maintenance planning, communication, and access to engineering information. Conversely, 6 participants (24.0%) expressed negative experiences, mainly due to technical limitations, inadequate digital infrastructure, insufficient training, and occasional system failures that affected routine engineering activities.

Participants with positive experiences explained that digital technologies had simplified engineering operations by providing timely access to maintenance information and improving coordination among engineering teams. They noted that digital monitoring systems enabled early detection of equipment faults, reduced unnecessary maintenance delays, and facilitated better planning of engineering activities. Several respondents emphasized that the availability of digital information improved the efficiency of maintenance scheduling and minimized unexpected equipment breakdowns, allowing engineers to focus more on preventive rather than corrective maintenance.

One marine engineer explained:

"…since digital technologies were introduced into some of our engineering activities, our daily work has become much more organized. We can monitor equipment conditions, access maintenance records quickly, and plan maintenance before serious failures occur. This has reduced unnecessary downtime and improved the way we coordinate engineering activities. Although some systems are still being improved, the technologies have made our work much more efficient than before..."

Similarly, a maintenance engineer stated:

"…digital systems have improved communication among maintenance teams because engineering information can now be shared much faster than when we relied entirely on manual records. We are able to identify maintenance priorities earlier, making it easier to allocate resources and complete maintenance work within the required time…"

These findings suggested that stakeholders who had positive experiences perceived digital technologies as valuable tools for improving engineering efficiency and maintenance effectiveness. Similar findings were reported in Europe and North America, where stakeholders experienced improvements in engineering coordination, predictive maintenance, and operational reliability following the adoption of digital technologies [9]. Comparable studies also found that digital technologies enhanced engineering communication, reduced equipment downtime, and strengthened maintenance planning within modern ports [11].

The majority of participants, however, described having mixed experiences with digital technologies. They acknowledged that although digital systems had introduced important improvements in engineering operations, their effectiveness was often constrained by incomplete system integration, occasional technical failures, inconsistent internet connectivity, and the coexistence of manual and digital procedures. Participants explained that while some engineering units benefited from advanced digital systems, others continued to depend largely on conventional maintenance practices, creating inconsistencies in engineering operations across the port.

One engineering manager explained:

"…digital technologies have certainly improved some aspects of engineering management, but our experience has been mixed because not every department has reached the same level of digitalization. Some engineering sections still use manual records while others operate digitally, making coordination more difficult than it should be. We have made progress, but there is still a long way to go before the systems are fully integrated..."

Another ICT officer added:

"…the technology has provided many benefits, but we occasionally experience system interruptions, software compatibility problems, and limited connectivity. During such periods, engineers are forced to return to manual procedures, which reduces the efficiency that digital technologies are supposed to provide…"

These findings indicated that stakeholders viewed digital transformation as an ongoing process rather than a completed initiative. Similar experiences were reported in Asian ports, where digital technologies improved maintenance coordination and engineering performance but required continuous investment in staff training, organizational readiness, and system integration to achieve maximum

effectiveness [12]. Other studies likewise emphasized that the successful implementation of digital technologies depended on adequate technical capacity and organizational support [13].

Some participants also reported negative experiences with digital technologies. These respondents explained that insufficient training, limited technical expertise, inadequate maintenance of digital systems, and occasional equipment failures reduced the effectiveness of digital technologies in supporting engineering operations. Participants further indicated that resistance to technological change among some employees slowed the adoption of new digital systems and affected their routine utilization.

One maintenance supervisor explained:

"...there are times when digital systems create more challenges than solutions because not everyone has received sufficient training to use them effectively. When technical problems occur, some employees become frustrated and return to manual methods because they are more familiar with them. This limits the benefits that the technologies are expected to deliver..."

Another senior technical officer stated:

"…some engineering equipment is still incompatible with newer digital technologies, making it difficult to integrate all maintenance activities into one system. We occasionally experience delays because digital tools are not fully synchronized with existing engineering operations…"

These findings demonstrated that the successful use of digital technologies depended not only on technological availability but also on user competence, organizational preparedness, and supporting infrastructure. Similar challenges were reported in African ports, where stakeholders identified limited digital infrastructure, inadequate technical expertise, and financial constraints as major barriers to effective digital technology utilization [14]. Comparable studies also found that continuous investment in digital infrastructure and workforce capacity was essential for improving engineering operations through digital transformation [15]. In Tanzania, previous studies similarly indicated that although digital technologies had improved operational coordination, many engineering activities continued to rely on conventional maintenance practices due to limited technological integration [16, 17].

The findings showed that stakeholders' experiences with digital technologies in daily marine engineering operations were largely mixed, reflecting both the opportunities and challenges associated with digital transformation at Dar es Salaam Port. While many participants acknowledged improvements in maintenance planning, equipment monitoring, communication, and operational coordination, others highlighted persistent challenges related to system integration, technical capacity, infrastructure limitations, and staff training. These findings suggest that achieving greater benefits from digital technologies will require continued investment in digital infrastructure, workforce development, and the integration of engineering systems to support efficient and sustainable marine engineering management.

4.2 Perceived influence of digital technologies on management efficiency

The findings explored stakeholders' perceptions of how digital technologies influenced marine engineering management efficiency at Dar es Salaam Port. The discussion focused on perceived improvements in operational performance as well as the influence of digital technologies on decision-making and resource optimization. Participants' responses provided valuable insights into the extent to which digital technologies were perceived to support efficient engineering operations, enhance management practices, and improve the utilization of engineering resources.

4.2.1 Perceived improvement in operational performance

The study revealed that stakeholders' perceptions regarding the influence of digital technologies on decision-making and resource optimization were varied, reflecting a complex integration process at Dar es Salaam Port. Of the 25 participants, 7 respondents (28.0%) perceived a high influence, 10 respondents (40.0%) reported a moderate influence, and 8 respondents (32.0%) indicated a low influence. These results as presented in Figure 3, indicated that while digital systems were recognized for their potential, their actual contribution to high-level engineering decision-making and resource optimization remained inconsistent.

Participants who perceived a high influence (7 respondents, 28.0%) pointed to the enhanced speed of information flow and improved transparency in routine maintenance tracking. A senior engineering manager noted:

"...the introduction of digital logs for our fleet services has been a genuine game-changer for our daily operations. Previously, we spent days manually reconciling maintenance records across different departments, which meant decisions about asset allocation were often based on outdated or incomplete information. Now, having a centralized digital overview allows us to see exactly which equipment is available and which requires immediate attention without waiting for paper reports. It has brought a new level of precision to how we deploy our teams and manage our spares, making our resource planning much more data-driven and responsive than it was in the past..."

This experience aligned with studies that highlighted how digital tools, such as big data analytics and automated systems, significantly improved resource optimization and decision-making in major Asian ports [20, 21]. These participants felt that digital integration provided the necessary visibility to shift from reactive to proactive management, directly supporting findings regarding the role of technology in increasing asset reliability and operational efficiency in global maritime hubs [19].

The second group of participants (10 respondents, 40.0%) reported a moderate influence on decision-making and resource optimization. These respondents appreciated the digitization of records but noted that the data often lacked the depth required for complex engineering forecasts. One technical supervisor explained:

"...we are definitely using digital tools more now, which has improved our daily coordination and helped us keep track of small repairs. However, the system currently acts more as a convenient digital archive than a true analytical engine that helps us look ahead. We can see what happened yesterday or last week, but the current tools don't yet give us the deep predictive insights needed to optimize our long-term maintenance budgets or anticipate major component failures. So, the influence is moderate; it helps with today's paperwork, but it doesn't fully support the strategic, complex decisions we need to make for future equipment upgrades or port expansion projects..."

This perception was consistent with studies that documented the potential for digital tools to improve information sharing in Tanzania, while simultaneously noting that engineering functions often lagged behind cargo-related logistics [24, 25]. Participants explained that the gap between basic digital record-keeping and advanced predictive analytics limited the transformative impact of these tools on strategic management.

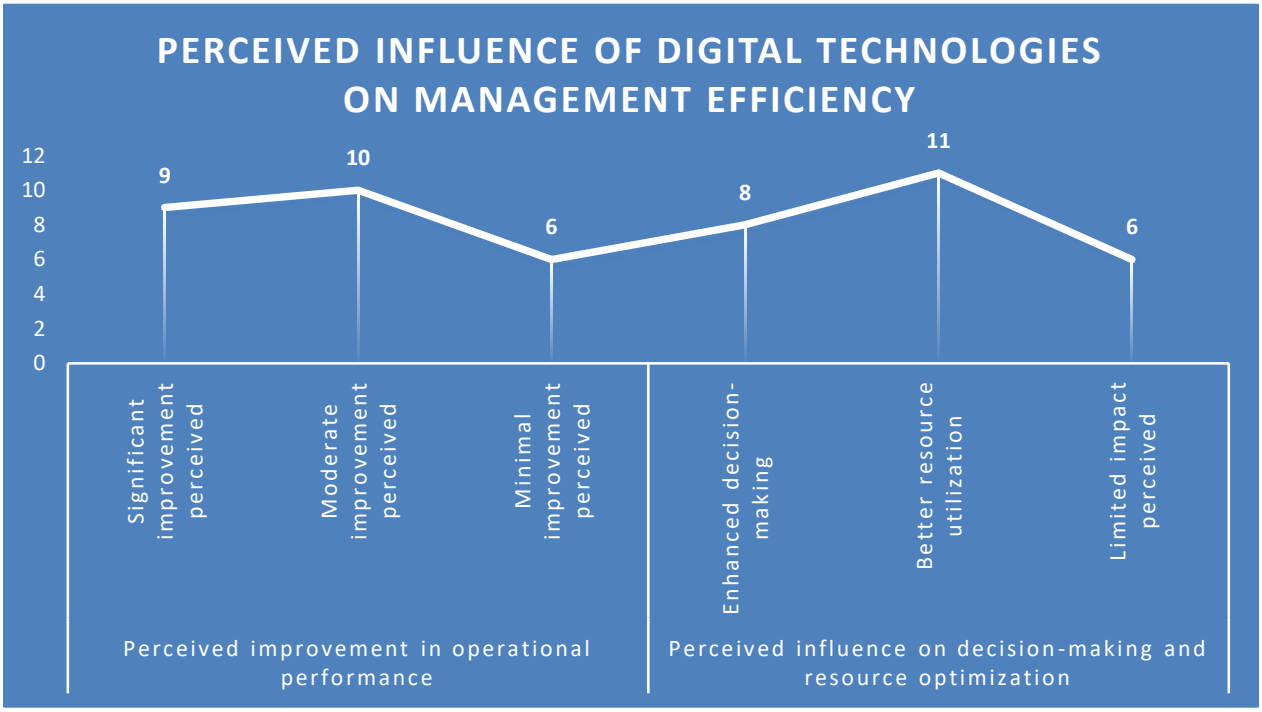

Figure 3: Showing the stakeholders' perceptions of how digital technologies influenced marine engineering management efficiency

A smaller group of 8 respondents (32.0%) felt the influence of digital technologies on decision-making was low. These participants cited technical integration gaps and the continued reliance on human intuition. One maintenance engineer noted:

"...for us, the technology is a secondary support tool at best, and we are not yet at a stage where it guides our most critical choices. When it comes to significant decisions regarding large-scale infrastructure repair or replacing expensive machinery, we still rely heavily on our own years of personal experience and manual inspection because the digital data we get is often incomplete, fragmented across different software, or simply inconsistent between departments. Until the systems are fully integrated and we can truly trust the real-time data being produced, I don't believe the technology is significantly changing or improving our core decision-making process at the management level..."

This view supported findings that the perceived benefits of digital technologies are frequently constrained by infrastructural readiness and technical expertise in many African ports [22, 23]. Respondents in this category believed that while the tools existed, they had not yet achieved the maturity level necessary to replace traditional, experience-based decision-making models.

The study showed that while digital technologies were increasingly utilized, their influence on decision-making and resource optimization remained largely confined to operational coordination rather than strategic management. Participants repeatedly emphasized that the transition from simple data collection to complex, predictive decision-making was hindered by system fragmentation and the need for more robust digital infrastructure. The experiences shared by participants pointed to the need for deeper integration of intelligent

maintenance systems and enhanced staff training to fully bridge the gap between local decision-making practices and the high-performance standards observed in global maritime engineering.

4.2.2 Perceived influence on decision-making and resource optimization

The findings revealed that stakeholders perceived digital technologies as having varying levels of influence on decision-making and resource optimization in marine engineering management at Dar es Salaam Port. Of the 25 stakeholders interviewed, 11 respondents (44.0%) perceived that digital technologies had resulted in better resource utilization, 8 respondents (32.0%) perceived that they had enhanced decision-making, while 6 respondents (24.0%) perceived that they had limited impact on decision-making and resource optimization. These findings, as presented in Figure 3, suggested that digital technologies had enabled engineering departments to improve the management of maintenance resources, optimize engineering activities, and support operational decisions. Nevertheless, participants acknowledged that the extent of these improvements depended on the level of technological integration, staff competencies, and the availability of reliable digital infrastructure.

Participants who perceived better resource utilization (11 respondents, 44.0%) explained that digital technologies had enabled engineering managers to allocate maintenance personnel, spare parts, financial resources, and engineering equipment more efficiently. They reported that access to real-time operational information helped managers prioritize maintenance activities according to the condition of engineering assets, thereby minimizing unnecessary maintenance costs and reducing equipment downtime. One Port Operations Manager explained:

"...before digital technologies were introduced, maintenance planning depended largely on routine schedules and physical inspections, which sometimes resulted in resources being allocated to equipment that did not require immediate attention. Today, engineering managers receive real-time operational information that enables them to identify priority maintenance requirements, assign technicians where they are most needed, and ensure that spare parts are used efficiently. This has reduced unnecessary maintenance costs and improved the utilization of both financial and human resources. We now spend our resources more strategically because decisions are supported by accurate operational information rather than assumptions."

The findings were consistent with studies conducted in Europe and North America, where stakeholders perceived that digital technologies optimized engineering resource allocation by providing timely operational information that supported maintenance planning and asset management [19]. Digital technologies were also found to improve operational efficiency by enhancing coordination among engineering departments and maximizing the utilization of available resources [18]. The participants' experiences suggested that digital transformation had enabled engineering managers to shift from routine resource allocation toward evidence-based management practices supported by real-time engineering information.

Another group of participants (8 respondents, 32.0%) perceived that digital technologies had primarily enhanced engineering decision-making. These stakeholders explained that digital systems had improved the quality, speed, and accuracy of engineering decisions because managers could access real-time equipment information, maintenance histories, and engineering performance data before making operational decisions. They indicated that engineering planning had become more objective because decisions were increasingly based on digital evidence rather than individual judgement alone. One Marine Engineering Manager stated:

"...engineering decision-making has improved considerably because digital technologies provide immediate access to operational information whenever maintenance issues arise. Instead of waiting for manual reports or conducting lengthy inspections, we can quickly assess equipment performance through digital systems and determine the most appropriate maintenance action. This has enabled us to respond faster to engineering problems, prioritize maintenance activities more accurately, and reduce delays that previously affected operational performance. Engineering decisions have become more reliable because they are supported by accurate and timely information."

These findings agreed with studies conducted in Asia, where stakeholders perceived that digital technologies strengthened engineering decision-making through intelligent maintenance systems, automation, and improved access to operational information [20]. Digital technologies were also reported to support evidence-based engineering planning by integrating predictive analytics, automation, and continuous monitoring of engineering assets [21]. The present findings therefore demonstrated that digital transformation had strengthened managerial confidence in engineering decision-making by improving the availability and quality of operational information.

A smaller proportion of participants (6 respondents, 24.0%) perceived that digital technologies had only a limited influence on decision-making and resource optimization. These respondents explained that although digital systems provided useful operational information, many engineering decisions continued to depend on managerial experience, manual verification, and conventional maintenance procedures. They further reported that occasional system failures, limited integration between engineering platforms, and inadequate staff training reduced the effectiveness of digital technologies in supporting management decisions. One Maintenance Engineer remarked:

"...digital technologies have certainly improved some aspects of engineering management, but their influence on decision-making is still limited because many engineering activities continue to rely on manual verification before final decisions are made. Sometimes digital systems experience technical problems or fail to provide complete operational information, forcing engineers to depend on personal experience and physical inspections. Until all engineering

systems become fully integrated and staff receive continuous training, digital technologies will not be able to support management decisions as effectively as expected."

These findings were comparable to studies conducted in Africa, where stakeholders recognized that digital technologies had improved engineering management but observed that inadequate technological infrastructure, limited technical expertise, and financial constraints continued to reduce their influence on decision-making and resource optimization [22]. Similar findings were reported in Tanzania, where digital technologies improved operational coordination and information sharing, although engineering management continued to experience challenges related to system integration and institutional capacity [24, 25]. Implementation challenges were also found to limit the effectiveness of digital transformation initiatives within Tanzanian ports [2].

The findings generally demonstrated that stakeholders perceived digital technologies as important tools for strengthening decision-making and optimizing engineering resources within marine engineering management. Participants emphasized that the availability of timely operational information had improved maintenance planning, engineering coordination, and resource allocation. However, they also noted that achieving the full benefits of digital technologies would require greater investment in integrated digital systems, continuous staff capacity development, and improvements in technological infrastructure to ensure that engineering decisions are consistently supported by reliable and comprehensive digital information.

5. CONCLUSION AND RECOMMENDATIONS

The study established that digital technologies had become increasingly important in supporting marine engineering management at Dar es Salaam Port, although their adoption and utilization varied across different engineering functions. Stakeholders reported that IoT sensors were the most widely used digital technology, followed by artificial intelligence analytics and CMMS, while blockchain technology remained at an early stage of implementation. Participants' experiences indicated that digital technologies had improved equipment monitoring, maintenance planning, engineering communication, and access to operational information. At the same time, the findings showed that challenges related to limited digital infrastructure, incomplete system integration, inadequate technical capacity, and continued reliance on conventional maintenance practices constrained the full realization of digital transformation within marine engineering management. The findings further revealed that stakeholders perceived digital technologies as contributing positively to management efficiency through improved operational performance, enhanced decision-making, and better utilization of engineering resources. The availability of real-time engineering information supported timely maintenance interventions, strengthened coordination among engineering personnel, and facilitated more efficient allocation of maintenance resources. Despite these benefits, participants emphasized that the influence of digital technologies remained uneven because some engineering processes had not yet been fully digitized and existing systems were not comprehensively integrated. These findings demonstrate that digital technologies have the potential to strengthen marine engineering management efficiency at Dar es Salaam Port when supported by effective implementation, integrated digital systems, and sustained organizational commitment.

The study recommended that the Tanzania Ports Authority should expand the adoption of digital technologies across all marine engineering functions by strengthening digital infrastructure and integrating engineering information systems to enhance operational efficiency. It further recommended continuous training and capacity building for marine engineers, ICT personnel, and maintenance staff to improve the effective utilization of digital technologies. Investment in advanced technologies such as IoT, artificial intelligence, Computerized Maintenance Management Systems (CMMS), and blockchain should be increased to support predictive maintenance, data-driven decision-making, and efficient resource utilization. The study also recommended establishing clear digital transformation strategies and continuous system monitoring mechanisms to ensure the sustainable implementation and optimal use of digital technologies in marine engineering management at Dar es Salaam Port.

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