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Evaluation of Risk Management Practices in Nigeria Liquefied Natural Gas Plant Maintenance in Bonny Island Rivers State Nigeria

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Abstract

This study evaluated risk management practices in civil infrastructure maintenance at Nigeria LNG Limited (NLNG), Bonny Island, Rivers State, with the aim of improving asset reliability and sustainable plant operations. The study specifically identified the major risks inherent in civil infrastructure maintenance, examined the risk management practices adopted, assessed the challenges affecting their effectiveness, and proposed sustainable strategies for improvement. The study was anchored on Risk Management Theory, Reliability-Centered Maintenance (RCM) Theory, and Asset Lifecycle Theory. A descriptive and analytical survey research design was adopted, while primary data were collected through structured questionnaires and interviews administered to fourteen (14) respondents selected from a population of fifteen (15) using the Taro Yamane formula. Data were analyzed using descriptive statistics, Relative Importance Index (RII), and Spearman Rank Correlation at a 5% level of significance. The findings revealed that corrosion, environmental exposure, ageing infrastructure, and harsh marine conditions constitute the major risks affecting civil infrastructure maintenance at NLNG. Routine inspections, preventive maintenance, risk assessments, Reliability-Centered Maintenance (RCM), and Risk-Based Maintenance (RBM) were identified as the principal risk management practices adopted, while inadequate maintenance funding, shortage of skilled personnel, operational pressures, ageing infrastructure, and limited deployment of digital monitoring technologies were found to hinder effective risk management. The study further established that sustainable practices such as predictive maintenance, lifecycle planning, digital monitoring systems, continuous staff training, and improved interdepartmental coordination significantly enhance infrastructure reliability and maintenance effectiveness. The study concluded that strengthening risk-based and technology-driven maintenance approaches is essential for improving asset integrity, operational safety, and sustainable plant operations at NLNG, and recommended greater investment in predictive maintenance technologies, maintenance funding, personnel development, and integrated risk management systems.

Keywords: *Risk management, Civil Infrastructure Maintenance, Nigeria LNG Limited (NLNG), Asset reliability, Reliability-Centered Maintenance (RCM), Risk-Based Maintenance (RBM).*

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Introduction

Risks in industrial systems can be broadly categorized into operational risks, structural risks, environmental risks, safety risks, and financial risks. In oil and gas facilities, these risks manifest through equipment failure, structural degradation, process upsets, environmental exposure, and human or organizational factors (Hopkin, 2018; Project Management Institute [PMI], 2017). Specifically, in Liquefied Natural Gas (LNG) facilities such as Nigeria LNG Limited (NLNG), risk exposure is heightened due to cryogenic processes, high pressure systems, marine operations, and continuous production requirements. Civil infrastructure within LNG plants is particularly exposed to environmental risks such as chloride induced corrosion, sulphate attack, carbonation, wave action, and differential settlement, especially in coastal and marine environments (Nguyen, Tran, & El-Gohary, 2022).

Nigeria LNG Limited (NLNG), located in Bonny Island, Rivers State, is one of Nigeria's most strategically significant gas processing and export facilities, contributing substantially to national revenue and global LNG supply. Commissioned in 1999 with subsequent expansion up to Train 6 in 2007, the facility has now operated for over two decades. As of 2026, much of its civil infrastructure has entered a mature lifecycle stage. Asset management standards emphasize that infrastructure performance becomes increasingly uncertain as assets age, particularly in aggressive operating environments, thereby increasing the likelihood of deterioration related failures (ISO, 2014).

The oil and gas industry operates within one of the most complex and high-risk industrial environments globally, characterized by high capital intensity, hazardous process conditions, tightly coupled systems, and minimal tolerance for failure. In such environments, risk is broadly defined as the effect of uncertainty on objectives, often expressed in terms of likelihood and consequence (International Organization for Standardization [ISO], 2018). Effective management of risk is therefore critical to ensuring operational reliability, asset integrity, safety, and environmental protection.

Infrastructure lifecycle risk studies indicate that ageing civil assets are subject to progressive and cumulative deterioration mechanisms that can significantly impair structural integrity if not proactively managed (Frangopol, Kallen, & van Noortwijk, 2004). Unlike mechanical systems that are periodically replaced, civil infrastructure including foundations, drainage systems, access roads, bund walls, culverts, hardstands, and marine structures remains in service throughout the plant lifecycle. This extended exposure increases susceptibility to degradation processes that are often gradual and not immediately detectable without structured inspection and monitoring systems (Nguyen et al., 2022).

To address such risks, maintenance strategies in high-risk industries have evolved toward structured and risk-based approaches. Risk management frameworks such as ISO 31000 provide systematic processes for risk identification, assessment, evaluation, treatment, monitoring, and review (ISO, 2018). At the organizational level, Enterprise Risk Management (ERM) integrates risk considerations into decision making across all functional units, improving coordination and risk visibility (Beasley, Clune, & Hermanson, 2005). Similarly, risk informed maintenance approaches emphasize prioritization of maintenance actions based on failure consequences and likelihood, thereby improving asset reliability and cost efficiency (de la Fuente & Gómez, 2014).

Empirical evidence in engineering asset management suggests that integrating risk-based methodologies into lifecycle planning enhances maintenance performance and reduces unplanned failures (Amadi Echendu et al., 2010). However, civil infrastructure presents unique challenges compared to mechanical systems. While mechanical failures are often sudden and detectable through condition monitoring technologies, civil infrastructure deterioration is typically gradual, cumulative, and influenced by environmental exposure and long-term loading conditions. Failure to detect early-stage deterioration significantly increases lifecycle costs and risk exposure (Nguyen et al., 2022).

Within the Nigerian perspective, existing studies have predominantly focused on construction project risks and contractor performance issues (Aibinu & Jagboro, 2002; Oke & Aigbavboa, 2017). In the oil and gas sector, research has examined maintenance strategy selection and decision-making models (Ighravwe & Oke, 2014), yet limited empirical attention has been given to risk management practices in civil infrastructure maintenance within operational LNG facilities. This gap is particularly critical as ageing infrastructure in facilities such as NLNG transitions into stages where deterioration related risks become more pronounced.

Infrastructure lifecycle theory suggests that risk exposure increases significantly during mid to late service life unless proactive, data driven, and risk-based maintenance systems are implemented (ISO, 2014; Frangopol et al., 2004). Given that NLNG's early trains are approaching three decades of operation, assessing the adequacy of existing risk management practices in civil infrastructure maintenance is essential for ensuring continued asset reliability, regulatory compliance, safety performance, and environmental sustainability.

Therefore, this study investigates risk management practices, challenges and prospects in NLNG plant maintenance, with specific focus on civil infrastructure assets. By examining the relationship between risk management practices and maintenance performance within an ageing LNG facility, the study aims to generate empirical evidence to support improved maintenance decision making, enhance asset sustainability, and bridge the gap between established risk management theory and practical implementation in high hazard industrial environments.

Statement of the Problem

Since its commissioning in 1999, Nigeria LNG Limited (NLNG) has relied on extensive civil infrastructure that has supported operations for over two decades. Unlike mechanical equipment that is periodically replaced, civil assets such as foundations, drainage systems, roads, and marine structures remain in service throughout the plant's lifecycle. Continuous exposure to environmental, structural, and operational stresses increases the risk of deterioration, failure, and operational disruptions.

Although risk management frameworks are implemented within the organisation, existing academic research in the oil and gas sector largely focuses on project and process related risks, with limited attention to civil infrastructure maintenance in operational LNG plants. Industry observations suggest that risk management for civil maintenance may be reactive, insufficiently data driven, and constrained by coordination and technological integration challenges. However, these concerns lack strong empirical validation.

This knowledge gap makes it difficult to assess whether existing risk management practices adequately mitigate long term civil infrastructure risks. Therefore, this study seeks to examine the practices, challenges, and prospects of risk management in NLNG civil maintenance, aiming to enhance asset reliability, safety, and sustainable plant operations.

Objectives of the Study

The main objective of this study is to examine risk management practices in NLNG civil infrastructure maintenance with a view to improving asset reliability and sustainable plant operations.

The specific objectives are to:

i. Identify the types of risks inherent in civil infrastructure maintenance at NLNG.
ii. Determine the risk management styles adopted to address civil infrastructure risks at NLNG.
iii. Examine the challenges affecting the effectiveness of risk management styles in civil infrastructure maintenance at NLNG.
iv. Propose sustainable strategies for enhancing risk management practices in civil infrastructure maintenance at Nigeria LNG Limited (NLNG).

Research Questions

This study seeks to provide answers to the following research questions:

i. What types of risks are inherent in civil infrastructure maintenance at NLNG?
ii. What risk management styles are adopted to address civil infrastructure risks at NLNG?

iii. What challenges affect the effectiveness of risk management styles in civil infrastructure maintenance at NLNG?
iv. What sustainable strategies can be adopted to enhance risk management practices in civil infrastructure maintenance at NLNG?

Research Hypotheses

The following null hypotheses will guide this study:

H_{01}: There is no significant relationship between identified risk types and the risk management styles adopted in civil infrastructure maintenance at NLNG.

H_{02}: Identified risk types do not significantly affect civil infrastructure maintenance performance at NLNG.

H_{03}: Implementation challenges do not significantly affect the effectiveness of risk management styles in civil infrastructure maintenance at NLNG.

H_{04}: Sustainable risk management practices do not significantly enhance asset reliability, safety performance, and sustainable plant operations at NLNG.

Scope of the Study

This study focuses on risk management practices, challenges, and prospects in civil infrastructure maintenance at Nigeria LNG Limited (NLNG), Bonny Island. It examines how risk identification, assessment, mitigation, and monitoring are applied to civil assets such as foundations, drainage systems, roads, hardstands, structural supports, buildings, bund walls, and marine facilities.

The study investigates the challenges affecting effective implementation of risk management in civil maintenance and explores prospects for strengthening risk-based maintenance to enhance asset reliability, safety performance, and sustainable plant operations.

The scope is limited to civil infrastructure within NLNG's operational facilities in Bonny Island, Rivers State, Nigeria. Mechanical and process safety systems are excluded except where they directly interface with civil infrastructure. The study considers maintenance activities from the commissioning of the plant in 1999 to 2024, particularly in the context of ageing infrastructure.

Review of Related Literature

Conceptual Review

Concept of Risk

Risk is a fundamental concept in engineering and asset management, particularly in high hazard industries such as oil and gas. According to the International Organization for Standardization (ISO, 2018), risk is defined as the effect of uncertainty on objectives typically expressed in terms of the likelihood of occurrence and the consequence of an event. This definition highlights that risk is not limited to negative outcomes but encompasses variability that may affect operational, financial, safety, and environmental objectives.

In industrial systems, risk is often conceptualized as a function of probability and consequence, where failures with low probability but high consequences such as structural collapse or containment failure require significant attention (Aven, 2016). Within oil and gas operations, risk is inherent due to complex process systems, hazardous materials, and harsh environmental conditions, making systematic risk identification and control essential.

Types of Risks in Civil Infrastructure Maintenance

Civil infrastructure such as (reinforced concrete foundations, access roads and internal road networks, hardstands, drainage systems, stormwater channels, Bund walls, containment structures, Buildings and control rooms, pipe rack structural support, marine jetties and loading berths, LNG tank foundations, perimeter fence, etc) in LNG facilities is exposed to multiple categories of risks that evolve over the asset lifecycle. These risks can be broadly classified as follows:

Structural Risks

Structural risks arise from deterioration mechanisms affecting the integrity of civil assets such as foundations, buildings, and marine structures. Common issues include cracking, reinforcement corrosion, fatigue, and settlement. Ageing infrastructure significantly increases susceptibility to such failures (Frangopol, Kallen, & van Noortwijk, 2004).

Environmental Risks

Environmental risks are particularly significant in coastal LNG facilities like NLNG. Exposure to chloride ingress, sulphate attack, humidity, and marine conditions accelerates material degradation, especially in reinforced concrete and steel structures (Nguyen, Tran, & El-Gohary, 2022).

Operational Risks

Operational risks relate to the interaction between infrastructure and plant operations, including loading conditions, vibration, accidental impacts, and process induced stresses. Poorly maintained infrastructure can disrupt operations and reduce plant availability (Hopkin, 2018).

Safety Risks

Failure of civil infrastructure can pose serious safety hazards, including structural collapse, falling objects, and compromised access routes, thereby endangering personnel and equipment (ISO, 2018).

Maintenance and Management Risks

These risks arise from inadequate inspection, poor maintenance planning, lack of data, or ineffective risk management practices. Such risks often contribute to delayed detection of deterioration and increased lifecycle costs (Amadi-Echendu et al., 2010).

Risk Management in Civil Infrastructure Maintenance

Risk management refers to the systematic process of identifying, analysing, evaluating, treating, monitoring, and reviewing risks that may hinder the achievement of organizational objectives (ISO, 2018). Within industrial asset intensive environments such as LNG plants, risk management provides a structured basis for decision making under conditions of uncertainty. It enables organizations to minimize threats, exploit opportunities, improve reliability, and sustain long term operational performance.

In civil infrastructure maintenance, risk management is particularly important because many infrastructure assets such as foundations, roads, drainage systems, marine structures, hardstands, bund walls, and buildings are designed for long service life and are continuously exposed to progressive deterioration mechanisms. Unlike mechanical failures that may occur suddenly and can often be rectified through replacement of components, deterioration in civil assets is usually gradual, cumulative, and less visible. Consequently, failure to proactively manage infrastructure risks may result in structural distress, production interruptions, safety incidents, environmental noncompliance, and increased lifecycle costs.

Effective risk management in civil infrastructure maintenance ensures that deterioration mechanisms are detected at an early stage, critical assets are prioritized, maintenance resources are optimally allocated, and corrective interventions are implemented before failures occur. This is especially important in LNG plants where the reliability of supporting civil infrastructure directly influences operational continuity, safety performance, and asset sustainability.

The risk management process generally consists of four interrelated stages: Risk identification, Risk assessment, Risk mitigation, and Risk monitoring and review.

Risk Identification

Risk identification is the process of recognizing, documenting, and describing potential events, conditions, or failure modes that may negatively affect the performance, integrity, or serviceability of civil infrastructure assets. In civil infrastructure maintenance, this stage involves identifying risks such as structural cracking, concrete spalling, reinforcement corrosion resulting from chloride ingress, differential settlement of foundations, drainage blockage, flooding, marine pile deterioration, overloading, vibration-induced fatigue, fire damage, impact damage, and climate-related risks such as coastal erosion, intense rainfall, and sea-level rise.

To identify such risks effectively, organizations employ several techniques including routine visual inspections, structural condition assessments, review of previous failure history, analysis of maintenance records, hazard identification studies (HAZID), checklists, expert judgement, non-destructive testing (NDT), asset registers, and integrity audits. In LNG facilities, risk identification is particularly important because deterioration in supporting structures may affect critical process equipment, storage systems, pipelines, and marine export infrastructure.

Risk Assessment

Risk assessment involves analysing identified risks to determine their likelihood of occurrence and the severity of their consequences. It assists organizations in distinguishing between tolerable risks and those requiring urgent intervention, while also identifying assets that demand higher maintenance priority.

In civil infrastructure maintenance, risk assessment typically considers two major dimensions: probability and consequence. Probability refers to the likelihood that a particular failure or deterioration event may occur. This may depend on factors such as asset age, environmental exposure conditions, loading intensity, inspection findings, historical failure records, design adequacy, and previous maintenance history.

Consequence refers to the potential impact if failure occurs. Such impacts may include injury or fatality, production downtime, damage to equipment, environmental pollution, regulatory penalties, escalation of repair costs, and reputational damage to the organization.

Several tools may be applied during risk assessment, including risk matrices that combine likelihood and consequence, condition rating models, remaining useful life estimation, structural reliability analysis, Failure Mode and Effects Analysis (FMEA), and quantitative risk scoring models. In LNG plants, the consequences of infrastructure failure are often significant because supporting civil assets are linked to hazardous operational systems. Therefore, even moderate-probability risks may justify immediate management attention.

Risk Mitigation

Risk mitigation involves the selection and implementation of measures designed to reduce the likelihood of risk occurrence, minimize consequences, transfer risk, or eliminate risk entirely. In civil infrastructure maintenance, mitigation measures may be preventive, corrective, engineering based, administrative, or strategic in nature.

Preventive measures include routine inspections, application of protective coatings, timely concrete repairs before severe deterioration develops, drainage cleaning programmes, corrosion protection systems, and scheduled preventive maintenance activities. These actions help slow deterioration and reduce the probability of failure.

Corrective measures are implemented when deterioration or failure has already occurred and may include structural strengthening, foundation stabilization, pavement reconstruction, replacement of damaged components, and emergency repairs. Such measures restore asset functionality and prevent escalation of damage.

Engineering controls involve physical, or design modifications intended to reduce exposure to risk. Examples include redesign of deficient structures, load redistribution, installation of flood protection systems, and cathodic protection systems for corrosion control.

Administrative controls include the use of maintenance procedures, permit to work systems, contractor supervision, competency training, and effective risk communication. These controls strengthen organizational discipline and reduce human-related errors.

Strategic measures are broader long-term actions that support sustainable infrastructure management. These include asset renewal planning, lifecycle budgeting, insurance or risk transfer arrangements, and adoption of advanced technologies such as sensors, digital monitoring systems, and predictive analytics.

Risk Monitoring and Review

Risk monitoring and review is the continuous process of tracking risk indicators, evaluating the effectiveness of implemented controls, and updating maintenance decisions as conditions change over time. This stage is particularly important for ageing civil infrastructure because deterioration is dynamic and progressive. Measures that are adequate today may become insufficient tomorrow if environmental exposure intensifies or asset condition declines.

Monitoring activities may include periodic inspections, structural health monitoring systems, crack width measurement, settlement surveys, corrosion potential testing, review of key performance indicators (KPIs), maintenance backlog assessments, incident and near-miss analysis, as well as audit and compliance reviews.

The review process ensures that risk registers remain current, maintenance priorities are updated, lessons learned from failures and inspections are incorporated into future planning, budgets are adjusted where necessary, and opportunities for continuous improvement are captured.

Risk Management Styles in Infrastructure Maintenance

Risk management styles refer to the approaches or frameworks used to manage risks in maintenance systems. In industrial asset management, several structured approaches are commonly applied:

Reliability Centre Maintenance (RCM)

Reliability-Centred Maintenance (RCM) is a structured, risk-based approach that focuses on maintaining the functional performance of assets by identifying critical components, analysing how they fail, and selecting appropriate maintenance strategies based on the consequences of failure (de la Fuente & Gómez, 2014). Unlike traditional time-based maintenance, RCM emphasizes function preservation, risk prioritization, and efficient resource utilization, making it suitable for high-risk environments such as LNG plants.

In civil infrastructure maintenance, RCM provides a systematic framework for managing ageing assets such as foundations, drainage systems, roads, marine structures, and bund walls. These assets are exposed to progressive deterioration, and RCM supports a shift from reactive maintenance to a proactive, performance-based approach.

The RCM process involves defining asset functions and performance standards, identifying functional failures, analysing failure modes, and evaluating the consequences of failure in terms of safety, operations, environment, and cost. Based on this evaluation, assets are classified by criticality to guide maintenance prioritization.

Appropriate maintenance strategies are then selected, including condition-based, preventive, predictive, or, where acceptable, run-to-failure approaches. These strategies are implemented through planned maintenance activities such as inspections, repairs, and rehabilitation works.

RCM also incorporates continuous monitoring and feedback, ensuring that maintenance decisions are regularly updated based on asset condition and performance data. This enhances early risk detection, improves maintenance effectiveness, and supports informed decision-making.

Risk-Based Maintenance (RBM)

Risk-Based Maintenance (RBM) is a systematic approach that integrates risk assessment into maintenance planning by prioritizing interventions based on the likelihood and consequences of asset failure (de la Fuente & Gómez, 2014). Unlike traditional maintenance approaches that rely on fixed schedules, RBM ensures that maintenance efforts are directed toward assets that pose the highest risk to safety, operations, and the environment. This makes it particularly relevant in oil and gas facilities where ageing infrastructure, hazardous processes, and continuous operations demand effective risk prioritization.

In civil infrastructure maintenance, RBM provides a structured framework for managing assets, the approach begins with risk identification and condition assessment, where potential failure modes and deterioration levels are established through inspections, historical data, and engineering evaluations. This is followed by risk analysis, where the probability of failure based on factors such as asset age, environmental exposure, loading conditions, and maintenance history is evaluated alongside the potential consequences of failure, including safety hazards, operational disruption, environmental impact, and economic loss. These two dimensions are combined, often using a risk matrix, to assign a risk ranking to each asset.

Based on the risk ranking, maintenance activities are prioritized, ensuring that high-risk assets receive immediate attention, while lower risk assets are managed with less intensive strategies. Appropriate maintenance actions may include condition-based inspections, preventive interventions, structural rehabilitation, or, where acceptable, deferred maintenance.

Preventive and Predictive Maintenance

Preventive and predictive maintenance are proactive strategies aimed at reducing the likelihood of asset failure and improving maintenance efficiency. Preventive maintenance involves planned and scheduled inspections, servicing, and minor repairs carried out at predetermined intervals to prevent deterioration from progressing to failure. Predictive maintenance, on the other hand, relies on condition monitoring, data analysis, and diagnostic techniques to determine the actual state of an asset and predict when maintenance should be performed (Carvalho, 2019).

Preventive maintenance typically includes routine inspections, drainage clearing, minor concrete repairs, joint sealing, and protective treatments aimed at slowing down deterioration and maintaining serviceability. While effective, preventive maintenance is often time based and may not fully reflect the actual condition of assets.

Predictive maintenance enhances this approach by incorporating condition-based techniques such as structural inspections, non-destructive testing, crack monitoring, settlement measurements, and corrosion assessment. These methods provide real time or periodic data that enable maintenance decisions to be based on actual asset condition rather than fixed schedules. As a result, interventions can be optimized to occur only when necessary, reducing unnecessary maintenance while preventing unexpected failures.

Enterprise Risk Management (ERM) Approach

Enterprise Risk Management (ERM) is an integrated framework that manages risks across all organizational levels in alignment with strategic objectives (Beasley, Clune, & Hermanson, 2005). It moves beyond isolated risk handling by ensuring that operational, financial, environmental, and infrastructure risks are addressed in a coordinated manner.

In civil infrastructure maintenance within LNG facilities, ERM links infrastructure-related risks such as deterioration of foundations, drainage systems, and marine structures to broader organizational priorities including safety, reliability, compliance, and cost efficiency. This ensures that maintenance decisions are not made in isolation but are aligned with overall business goals.

ERM involves systematic risk identification, assessment, response, and continuous monitoring, supported by tools such as risk registers and performance indicators. It also promotes cross-functional coordination and a risk aware organizational culture.

Challenges Affecting Risk Management in Civil Infrastructure Maintenance

Despite the availability of structured risk management frameworks, their effective implementation in civil infrastructure maintenance is often constrained by several practical challenges. These challenges are more pronounced in ageing infrastructure, complex operations, and developing economies, where institutional, technical, and resource limitations may hinder optimal application of risk-based approaches.

Data Limitations

Effective risk management relies heavily on the availability of accurate, reliable, and up-to-date data on asset condition, failure history, and maintenance performance. However, in many civil infrastructure systems, particularly long-life assets, historical data is often incomplete, inconsistent, or poorly documented. This limits the ability to perform reliable risk assessments, estimate failure probabilities, and implement predictive maintenance strategies. Nguyen, Tran, and El-Gohary (2022) emphasize that inadequate data significantly undermines condition-based and risk-informed decision making, leading to increased uncertainty and reactive maintenance practices. In LNG facilities, where infrastructure deterioration is gradual and not always visible, the absence of robust data systems can delay early detection of defects and compromise long term asset reliability.

Organizational and Coordination Challenges

Risk management in civil infrastructure maintenance requires effective coordination among multiple functional units, including engineering, maintenance, operations, and management. However, organizational silos, unclear roles, and poor communication often hinder the integration of risk management processes. Hopkin (2018) notes that fragmented organizational structures can lead to inconsistent risk reporting, duplication of efforts, and delays in decision making. In practice, this may result in maintenance activities that are not aligned with operational priorities or risk exposure levels. Within LNG operations, where infrastructure supports critical process systems, lack of coordination can reduce the effectiveness of risk mitigation measures and increase the likelihood of system-wide disruptions

Technological Constraints

The effectiveness of modern risk management approaches is increasingly dependent on the use of advanced technologies such as structural health monitoring systems, non-destructive testing (NDT), digital asset management platforms, and data analytics tools. However, limited adoption of these technologies remains a significant challenge in many organizations. This constraint reduces the ability to detect early-stage deterioration, monitor asset performance in real time, and implement predictive maintenance strategies. According to Nguyen et al. (2022), the integration of digital technologies is essential for improving infrastructure risk assessment and lifecycle management, yet implementation is often constrained by cost, technical expertise, and system compatibility issues. In LNG environments, where assets are exposed to harsh conditions, the absence of advanced monitoring systems increases dependence on manual inspections, which may not always provide timely or accurate information.

Resource Constraints

Resource limitations, particularly in terms of budget, skilled personnel, and time, represent a major barrier to effective risk management in civil infrastructure maintenance. Competing operational priorities often lead to deferred maintenance, where necessary interventions are postponed due to financial constraints or production demands. Amadi-Echendu et al. (2010) highlight that such deferrals can result in accelerated deterioration, increased failure risk, and higher long-term maintenance costs. In asset intensive industries like LNG, where infrastructure plays a critical supporting role, inadequate resource allocation can compromise both safety and operational efficiency. Furthermore, shortages of skilled personnel may affect the quality of inspections, risk assessments, and maintenance execution, thereby reducing the overall effectiveness of risk management systems.

Sustainable Risk Management in Civil Infrastructure Maintenance

Sustainable risk management involves adopting long term, proactive approaches that ensure infrastructure reliability, safety, and environmental protection throughout the asset lifecycle. It integrates risk-based maintenance with sustainability principles such as resource optimization, lifecycle cost management, and resilience.

According to ISO 55000 (2014), effective asset management requires balancing performance, risk, and cost over the asset lifecycle. Sustainable maintenance approaches therefore emphasize:

i. Lifecycle based planning
ii. Proactive deterioration management
iii. Integration of digital technologies
iv. Continuous improvement of risk management systems

Empirical studies indicate that organizations that adopt risk based and lifecycle-oriented maintenance strategies achieve improved asset performance and long-term operational sustainability (de la Fuente & Gómez, 2014).

Theoretical Framework

A theoretical framework provides the lens through which a study interprets and analyses its subject matter. For this research on risk management practices, challenges, and prospects in civil infrastructure maintenance at NLNG, three key theories provide the conceptual foundation:

Risk Management Theory

Risk Management theory highlights the identification, evaluation, and treatment of uncertainties that may hinder the achievement of organizational objectives (ISO, 2018). The theory posits that structured and proactive risk management improves decision making, reduces uncertainty, and minimizes the likelihood and impact of adverse events. In asset intensive environments such as LNG plants, it provides a logical framework for managing risks associated with ageing infrastructure, complex operations, and hazardous conditions.

The theory supports this study by explaining how different categories of risk associated with civil infrastructure maintenance such as structural, environmental, operational, and safety risks should be identified, analysed, and managed in an integrated manner. It emphasizes proactive intervention, continuous monitoring, and alignment of maintenance decisions with overall organizational objectives (Aven, 2016; ISO, 2018).

A central element of the theory is risk identification, which involves recognizing potential hazards and understanding their origin and impact pathways. For instance, corrosion is a major risk in civil infrastructure, particularly in coastal LNG environments. It occurs when aggressive agents such as chlorides penetrate concrete and reach embedded steel reinforcement, initiating electrochemical reactions that lead to rust formation. This process causes expansion of the steel, resulting in cracking, delamination, and eventual spalling of the concrete cover. Corrosion becomes a significant risk because it progressively reduces the structural capacity of the asset and can lead to failure if not controlled. Moreover, its effects are not isolated; deterioration of structural supports can compromise connected systems such as pipelines, storage tanks, and marine loading facilities, thereby affecting overall plant operations and safety.

Similarly, other risks such as cracking, fatigue, and differential settlement arise from environmental exposure, loading conditions, or design limitations. Cracking may allow ingress of moisture and chemicals, accelerating corrosion; fatigue results from repeated loading cycles, gradually weakening structural elements, while settlement can lead to misalignment and structural stress. These risks are often interrelated, meaning that the occurrence of one can trigger or accelerate others, thereby increasing overall system vulnerability.

The next component, risk analysis, involves evaluating the likelihood of these risks occurring and the severity of their consequences. This includes assessing factors such as asset age, environmental exposure, inspection findings, and historical performance, alongside potential impacts on safety, operations, environment, and cost. The outcome of this analysis provides a basis for prioritizing maintenance actions.

Risk treatment focuses on selecting and implementing appropriate measures to manage identified risks. In civil infrastructure maintenance, this may involve preventive actions such as routine inspections and protective treatments, predictive approaches based on condition monitoring, or corrective interventions such as repairs and structural strengthening. The objective is to reduce risk to an acceptable level while optimizing maintenance resources.

Risk monitoring ensures continuous tracking of asset condition and effectiveness of implemented measures. Through inspections, performance indicators, and feedback systems, maintenance strategies are regularly updated to reflect changing conditions and emerging risks.

This theory aligns directly with the objectives by providing a framework for understanding and improving civil infrastructure maintenance practices through structured risk assessment and management.

Reliability Centered Maintenance (RCM) Theory

Reliability Centered Maintenance (RCM) is a maintenance strategy that prioritizes maintenance activities based on the consequences of failure and asset criticality (Moubray, 1997; modern applications: de la Fuente & Gómez, 2014). The theory posits that not all failures are equal; maintenance should focus on functions that are critical to operational performance, safety, and asset integrity.

In civil infrastructure maintenance at NLNG, RCM theory provides a conceptual basis for Objective 1 and Objective 3 by:

i. Classifying assets according to their functional importance.
ii. Determining maintenance interventions based on risk exposure rather than fixed schedules.
iii. Supporting cost effective maintenance planning while ensuring reliability and safety.

RCM complements Risk Management Theory by linking risk assessment outcomes to practical maintenance decision making, thereby improving the efficiency of civil infrastructure upkeep.

Asset Lifecycle Theory

Asset Lifecycle Theory (ALT) emphasizes that infrastructure performance, risk exposure, and maintenance requirements change over the life of an asset from commissioning to decommissioning (ISO 55000, 2014; Kumar, Zuo & Makarov, 2021). The theory suggests that:

i. Early-stage maintenance focuses on installation quality and defect rectification.
ii. Mid-life maintenance addresses progressive deterioration and operational stresses.
iii. Late life maintenance focuses on structural integrity, lifecycle extension, and risk mitigation.

For NLNG's civil infrastructure, ALT supports Objective 2 and Objective 3 by highlighting the need to:

i. Identify challenges that arise as assets age.
ii. Implement sustainable risk-based maintenance practices.
iii. Optimize asset reliability, safety, and long-term operational sustainability.

This lifecycle perspective provides a holistic view, linking asset age, environmental exposure, and operational context to maintenance planning and risk mitigation strategies.

Integration of Theories

By combining these three theories, the study establishes a robust framework:

Table 1: Integration of Theories and Study Objectives

Theory	Contribution to Study	Linked Objectives
Risk Management Theory	Provides tools for identifying and managing risks systematically	Objective 1
Reliability Centered Maintenance	Connects risk prioritization to maintenance actions	Objective 2
Asset Lifecycle Theory	Explains how ageing infrastructure affects risk and maintenance needs	Objective 3 & 4

Source: Researcher's Compilation (2026) from Risk Management Theory (ISO, 2018; Aven, 2016), Reliability-Centered Maintenance Theory (Moubray, 1997; de la Fuente & Gómez, 2014), and Asset Lifecycle Theory (ISO 55000, 2014; Kumar, Zuo, & Makarov, 2021).

Empirical Review

The empirical review examines previous research and real-world studies on risk management practices, challenges, and improvement prospects in civil infrastructure maintenance. The review is organized according to the three research objectives.

Empirical Studies on Types of Risks in Civil Infrastructure Maintenance (Objective 1)

Previous studies identify structural, environmental, operational, and safety risks as major threats to civil infrastructure performance in industrial facilities.

Amadi-Echendu et al. (2010) found that infrastructure reliability improves when risks are systematically identified and prioritized. Nguyen, Tran, and El-Gohary (2022) observed that corrosion, fatigue, environmental degradation, and climate-related exposure significantly affect infrastructure integrity, particularly in coastal and marine environments. Frangopol, Kallen, and van Noortwijk (2004) further established that deterioration is progressive and cumulative, especially in ageing infrastructure exposed to harsh environmental conditions.

Similarly, Kumar, Zuo, and Makarov (2021) showed that infrastructure failure probability increases with asset age, environmental exposure, and operational loading, emphasizing the need for proactive maintenance and continuous condition monitoring. Hopkin (2018) also noted that operational risks such as excessive loading, vibration, accidental impacts, and process-related stresses can significantly affect infrastructure performance and operational reliability.

These studies collectively indicate that civil infrastructure in LNG facilities is exposed to multiple interconnected risks, particularly in ageing and environmentally aggressive operating conditions.

Empirical Studies on Risk Management Styles in Civil Infrastructure Maintenance (Objective 2)

Several studies have examined the effectiveness of structured risk management styles in improving infrastructure maintenance performance.

De la Fuente and Gómez (2014) found that Reliability-Centred Maintenance (RCM) and Risk-Based Maintenance (RBM) improve maintenance prioritization, optimize resource allocation, and reduce unexpected failures. Carnero and Gómez (2021) established that predictive maintenance and risk-based approaches improve asset reliability, reduce downtime, and enhance cost efficiency through effective condition monitoring.

Beasley, Clune, and Hermanson (2005) observed that Enterprise Risk Management (ERM) improves coordination and risk visibility across organizational units, thereby supporting better maintenance decision-making. Carvalho (2019) also demonstrated that predictive maintenance strategies improve infrastructure availability and reduce maintenance costs through early detection of deterioration.

Overall, the studies show that structured approaches such as RCM, RBM, predictive maintenance, preventive maintenance, and ERM significantly improve maintenance effectiveness when properly implemented.

Empirical Studies on Challenges Affecting Risk Management Styles (Objective 3)

Despite the benefits of structured risk management approaches, several studies identified major implementation challenges.

De la Fuente and Gómez (2014) and Nguyen et al. (2022) found that inadequate monitoring systems and limited infrastructure data reduce the effectiveness of risk assessment and predictive maintenance. Beasley et al. (2005) identified poor coordination, fragmented communication, and unclear responsibilities as major organizational barriers.

Kumar et al. (2021) further noted that ageing infrastructure increases uncertainty and complexity in maintenance planning. Ighravwe and Oke (2014) found that budget limitations and competing operational priorities often result in deferred maintenance decisions, thereby increasing infrastructure risks. Similarly, Eke, Aigbavboa, and Thwala (2021) concluded that risk management practices in Nigeria are often reactive due to limited technical expertise, weak institutional structures, and inadequate technology adoption.

These findings indicate that data limitations, organizational challenges, ageing infrastructure, technological constraints, and resource limitations significantly affect effective risk management implementation.

Empirical Studies on Sustainable Approaches for Improving Risk Management Practices (Objective 4)

Empirical literature identifies several sustainable approaches for improving infrastructure maintenance and long-term operational reliability.

Kumar et al. (2021) demonstrated that integrating lifecycle models with monitoring systems enhances predictive maintenance and asset reliability. Nguyen et al. (2022) highlighted the importance of digital technologies such as BIM, sensors, structural health monitoring systems, and predictive analytics in improving risk detection and maintenance decision-making.

Carnero and Gómez (2021) found that sustainability-oriented maintenance strategies improve asset lifecycle performance and operational continuity. Aven (2016) emphasized the importance of organizational risk culture and proactive decision-making, while Beasley et al. (2005) observed that integrated risk frameworks improve coordination, accountability, and long-term infrastructure sustainability.

Overall, the studies suggest that digitalization, lifecycle planning, predictive maintenance, organizational integration, and continuous improvement can significantly enhance civil infrastructure reliability, safety performance, and sustainable plant operations in LNG facilities.

Summary of Empirical Review and Research Gap

Summary of Empirical Review:

The empirical review revealed that civil infrastructure in industrial facilities is exposed to structural, environmental, operational, and safety risks. Studies identified corrosion, fatigue, environmental exposure, excessive loading, and ageing infrastructure as major causes of deterioration and infrastructure failure (Frangopol et al., 2004; Nguyen et al., 2022; Kumar et al., 2021).

The review further showed that structured risk management styles such as Reliability Centred Maintenance (RCM), Risk Based Maintenance (RBM), preventive maintenance, predictive maintenance, and Enterprise Risk Management (ERM) improve infrastructure reliability, maintenance prioritization, operational efficiency, and cost effectiveness when properly implemented (de la Fuente & Gómez, 2014; Carnero & Gómez, 2021).

However, several implementation challenges were identified, including inadequate infrastructure data, poor organizational coordination, ageing infrastructure complexity, technological limitations, budget constraints, and shortage of skilled personnel (Beasley et al., 2005; Ighravwe & Oke, 2014; Eke et al., 2021).

The review also established that sustainable improvement in infrastructure maintenance can be achieved through lifecycle-based planning, digital technologies, predictive maintenance, structural health monitoring systems, and integrated organizational risk management frameworks.

Identified Research Gap:

Despite the substantial body of literature on risk management and infrastructure maintenance, several gaps remain evident.

First, most existing studies focus broadly on construction projects, mechanical systems, or general asset management, with limited empirical attention given specifically to civil infrastructure maintenance within operational LNG facilities in Nigeria.

Second, although several studies discuss infrastructure deterioration and maintenance strategies, limited research has examined the specific types of risks affecting ageing civil infrastructure in coastal LNG environments such as NLNG, where environmental exposure significantly accelerates deterioration.

Third, while studies have examined various risk management styles, there is inadequate empirical evidence on the effectiveness of these approaches within real operational LNG environments, particularly in relation to civil infrastructure maintenance.

Finally, limited studies have comprehensively examined the combined influence of implementation challenges, organizational constraints, ageing infrastructure, and sustainability focused improvement strategies on civil infrastructure risk management within the Nigerian oil and gas sector.

This study therefore seeks to bridge these gaps by providing empirical evidence on the types of risks affecting civil infrastructure, the risk management styles adopted, the challenges affecting their effectiveness, and sustainable approaches for improving civil infrastructure maintenance practices at NLNG, Bonny Island.

Methodology

Research Design

This study adopts a descriptive and analytical survey research design. The descriptive aspect enables the identification of risk types and management styles in civil infrastructure maintenance, while the analytical component allows for the examination of relationships between variables such as risk management practices, implementation challenges, and maintenance outcomes.

The survey design is appropriate because it facilitates the collection of primary data from professionals involved in civil infrastructure maintenance at NLNG. It also supports quantitative analysis required for testing the study’s hypotheses.

Area of Study

The study is conducted at Nigeria LNG Limited (NLNG), Bonny Island, Rivers State, Nigeria. Bonny Island is located within the Niger Delta region and is characterized by a tropical monsoon climate with high temperatures, heavy rainfall, and high humidity levels throughout most of the year.

The coastal and marine environment exposes civil infrastructure to aggressive environmental conditions such as chloride attack, sulphate attack, salt laden air, and tidal influences, all of which accelerate corrosion and deterioration of reinforced concrete and steel structures. In addition, the predominantly soft and waterlogged soil conditions increase the risk of differential settlement and foundation instability.

These environmental and geotechnical characteristics make Bonny Island a suitable location for studying risks associated with civil infrastructure maintenance within LNG operations.

Sources of Data

The study utilized primary and secondary data sources.

Primary data were be obtained through:

i. Structured questionnaires shared to relevant personnel.
ii. Interviews to support clarification of responses.

While the secondary data are information from related literature from previous work.

Population of the Study

The population of the study comprised of relevant personnel involved in civil infrastructure maintenance and related risk management activities at NLNG.

This includes:

i.	Civil Engineers	=	3
ii.	Maintenance Engineers	=	3
iii.	Project/Asset management Engineers	=	2
iv.	Supervisors and Planners	=	3
v.	HSE personnel involved in infrastructure risk management	=	2
vi.	Maintenance team leads	=	2

The population were selected because these individuals possess the technical knowledge and practical experience required to provide reliable data for the study.

Determination of Sample Size

The sample size for the study was determined using the Taro Yamane (1967) formula, which is appropriate for finite populations:

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

Where:

n = sample size

N = population size (15)

e = margin of error / level of significance (0.05)

Step-by-step calculation:

$$n = \frac{15}{1 + 15(0.05)^2}$$
$$n = \frac{15}{1 + 15(0.0025)}$$
$$n = \frac{15}{1 + 0.0375}$$
$$n = \frac{15}{1.0375}$$
$$n = 14.4578 \approx 14.46$$

$$\boxed{n \approx 14.46}$$

This method ensures that the selected sample is statistically representative of the study population.

Sampling Techniques

The study adopted a combination of purposive and simple random sampling techniques. Purposive sampling was used to identify personnel directly involved in civil infrastructure maintenance and risk management activities within NLNG. Thereafter, simple random sampling was employed to select respondents from the identified population to ensure fairness and reduce selection bias.

Method of Data Collection

Data were collected using a structured questionnaire and interviews designed based on the study objectives and hypotheses.

The questionnaire consists of:

Section A: Demographic information

Section B: Types of Risks in Civil Infrastructure Maintenance

Section C: Risk Management styles adopted in Civil Infrastructure Maintenance

Section D: Challenges affecting Risk Management

Section E: Sustainable Approaches for Improvement

Section F: Open Ended Questions

Responses were measured using a 5-point Likert scale, ranging from:

Strongly Agree (5) to Strongly Disagree (1)

Very Significant (5) to Not Significant (1)

Very High (5) to Very Low (1).

Validity of the Instrument

Validity refers to the extent to which the instrument measures what it is intended to measure.

The questionnaire was subjected to content and face validity through:

i. Review by academic experts
ii. Review by industry professionals in civil infrastructure maintenance

Their feedback ensured that the instrument adequately captures the variables under study.

Reliability of the Instrument

Reliability refers to the consistency of the measurement instrument.

The reliability of the questionnaire will be tested using Cronbach's Alpha, which measures internal consistency. A reliability coefficient of 0.70 and above will be considered acceptable for the study.

Method of Data Analysis

Data collected for the study were analysed using descriptive statistics including frequency distribution, percentages, mean score, ranking, and Relative Importance Index (RII). The hypotheses were tested using Spearman Rank Correlation due to the small sample size and ordinal nature of the Likert-scale data. Qualitative responses from open-ended questions were analysed using thematic/content analysis."

Decision Rule

The decision rule for testing the hypotheses in this study is based on a 5% level of significance (0.05). Therefore:

i. If the calculated p-value is less than 0.05 ($p < 0.05$), the null hypothesis (H_0) will be rejected, indicating that there is a statistically significant relationship or effect between the variables under study.
ii. If the calculated p-value is greater than or equal to 0.05 ($p \geq 0.05$), the null hypothesis (H_0) will not be rejected, indicating that there is no statistically significant relationship or effect between the variables under study.

Data Presentation and Analysis

This section presents the analysis and interpretation of data collected from respondents. The data obtained from the questionnaires were analysed using descriptive statistics including frequency distribution, percentages, mean score, ranking, Relative Importance Index (RII), and qualitative analysis. The hypotheses were tested using Spearman Rank Correlation at 5% level of significance. The analysis was based on the completed questionnaires retrieved from respondents.

Data Presentation

A total of fifteen (15) questionnaires were distributed to personnel involved in civil infrastructure maintenance activities at Nigeria LNG Limited. Out of the questionnaires distributed, fourteen (14) were properly completed and returned, representing a response rate of 93.3%, while one questionnaire was invalid for analysis.

Demographic Characteristics of Respondents
Table 2: Gender Distribution of Respondents

Gender	Frequency	Percentage (%)
Male	12	85.7
Female	2	14.3
Total	14	100

The result in Table 2 shows that majority of respondents were male, accounting for 85.7%, while female respondents accounted for 14.3%. This reflects the dominance of male personnel within engineering and maintenance operations in LNG facilities.

Table 3: Age Distribution of Respondents

Age Range (Year)	Frequency	Percentage (%)
20–30	0	0
31–40	4	28.6
41–50	7	50.0
51 and above	3	21.4
Total	14	100

The result indicates that majority of respondents were within the age bracket of 41–50 years, suggesting that respondents possessed considerable professional and maintenance experience relevant to the study.

Table 4: Educational Qualification of Respondents

Qualification	Frequency	Percentage (%)
HND/BSc	7	50.0
MSc	7	50.0
PhD	0	0
Others	0	0
Total	14	100

The result reveals that all respondents possessed tertiary education qualifications, indicating that respondents had adequate technical and academic knowledge relevant to infrastructure maintenance and risk management.

Table 5: Years of Experience of Respondents

Years of Experience	Frequency	Percentage (%)
1-5	0	0
6-10	3	21.4
11-15	3	21.4
16 and above	8	57.2
Total	14	100

The result indicates that majority of respondents had over 16 years of experience, implying that the responses were obtained from experienced personnel familiar with civil infrastructure maintenance operations at NLNG.

Table 6: Job Role Distribution of Respondents

Job Role	Frequency	Percentage (%)
Engineer	8	57.1
Planner	2	14.3
Team Lead	2	14.3
HSE	1	7.1
Supervisor	1	7.1
Manager	0	0
Total	14	100

The result shows that engineers constituted the highest percentage of respondents, indicating that the study relied heavily on technically experienced personnel directly involved in maintenance and infrastructure management activities.

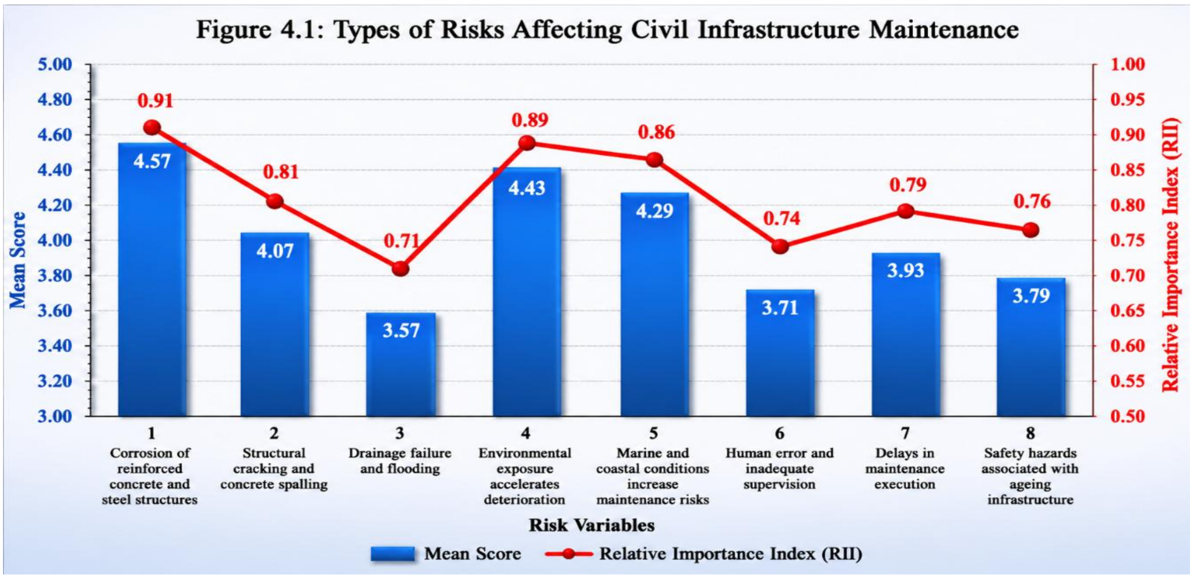
Data Analysis

Types of Risks in Civil Infrastructure Maintenance

Table 7: Types of Risks Affecting Civil Infrastructure Maintenance

S/N	Risk Variables	Mean Score	RII	Rank
1	Corrosion of reinforced concrete and steel structures is a major infrastructure risk	4.57	0.91	1
2	Structural cracking and concrete spalling frequently affect infrastructure performance	4.07	0.81	4
3	Drainage failure and flooding pose operational risks to the facility	3.57	3.57	8
4	Environmental exposure accelerates infrastructure deterioration	4.43	0.89	2
5	Marine and coastal conditions increase infrastructure maintenance risks	4.29	0.86	3

6	Human error and inadequate supervision contribute significantly to maintenance risks	3.71	0.74	7
7	Delays in maintenance execution increase infrastructure risk exposure	3.93	0.79	5
8	Safety hazards associated with ageing infrastructure are increasing	3.79	0.76	6



The findings reveal that corrosion of reinforced concrete and steel structures, environmental exposure, and marine/coastal conditions are the most significant risks affecting civil infrastructure maintenance at NLNG. This is attributable to the aggressive coastal and marine environment of Bonny Island.

Risk Management Styles Adopted in Civil Infrastructure Maintenance

Table 8: Risk Management Styles Adopted

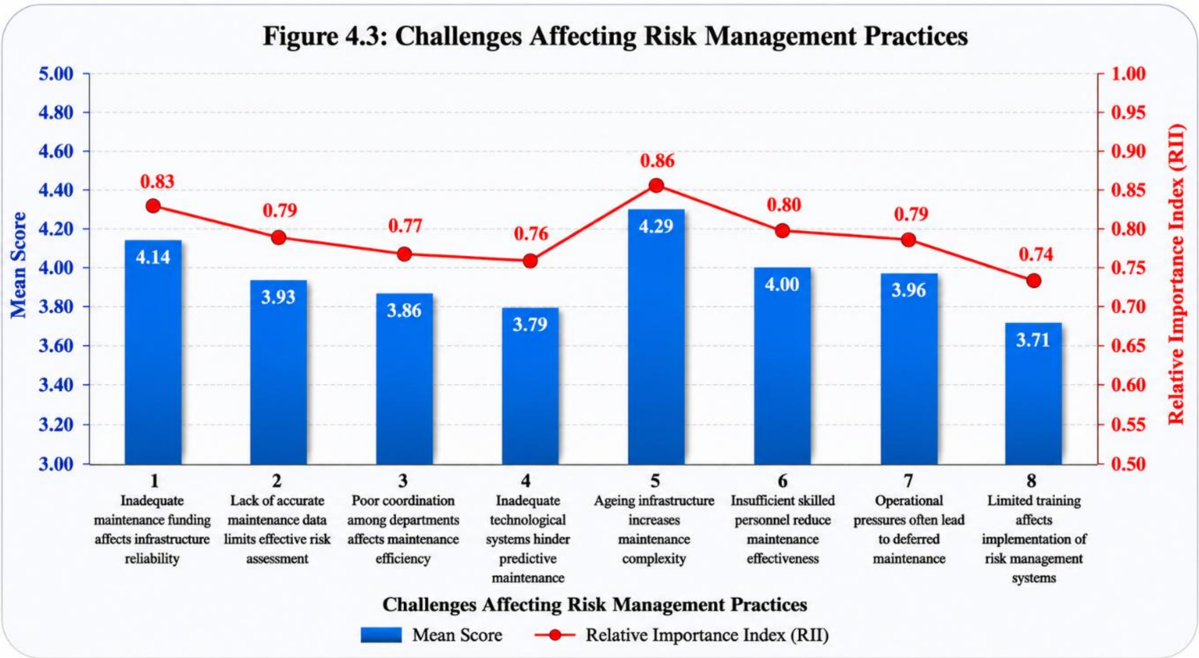
S/N	Variables	Mean Score	RII	Rank
1	Routine infrastructure inspections are regularly conducted	4.64	0.93	1
2	Preventive maintenance is effectively implemented for civil assets	4.43	0.89	3
3	Risk assessments are conducted before major maintenance activities	4.5	0.9	2
4	Risk registers are maintained and updated periodically	4	0.8	7
5	Reliability-Centered Maintenance (RCM) principles are applied	4.14	0.83	5
6	Risk-Based Maintenance (RBM) is used to prioritize maintenance activities	4.21	0.84	4
7	Maintenance decisions are aligned with organizational safety objectives	4.07	0.81	6
8	Digital technologies are integrated into infrastructure risk monitoring	3.64	0.73	8

The findings indicate that routine inspections, preventive maintenance, and pre-maintenance risk assessments are the dominant risk management approaches adopted in civil infrastructure maintenance at NLNG. However, digital monitoring technologies remain less integrated into maintenance systems.

Challenges Affecting Risk Management Practices

Table 9: Challenges Affecting Risk Management Practices

S/N	Variables	Mean Score	RII	Rank
1	Inadequate maintenance funding affects infrastructure reliability	4.14	0.83	2
2	Lack of accurate maintenance data limits effective risk assessment	3.93	0.79	5
3	Poor coordination among departments affects maintenance efficiency	3.86	0.77	6
4	Inadequate technological systems hinder predictive maintenance	3.79	0.76	7
5	Ageing infrastructure increases maintenance complexity	4.29	0.86	1
6	Insufficient skilled personnel reduce maintenance effectiveness	4	0.8	3
7	Operational pressures often lead to deferred maintenance	3.96	0.79	4
8	Limited training affects implementation of risk management systems	3.71	0.74	8

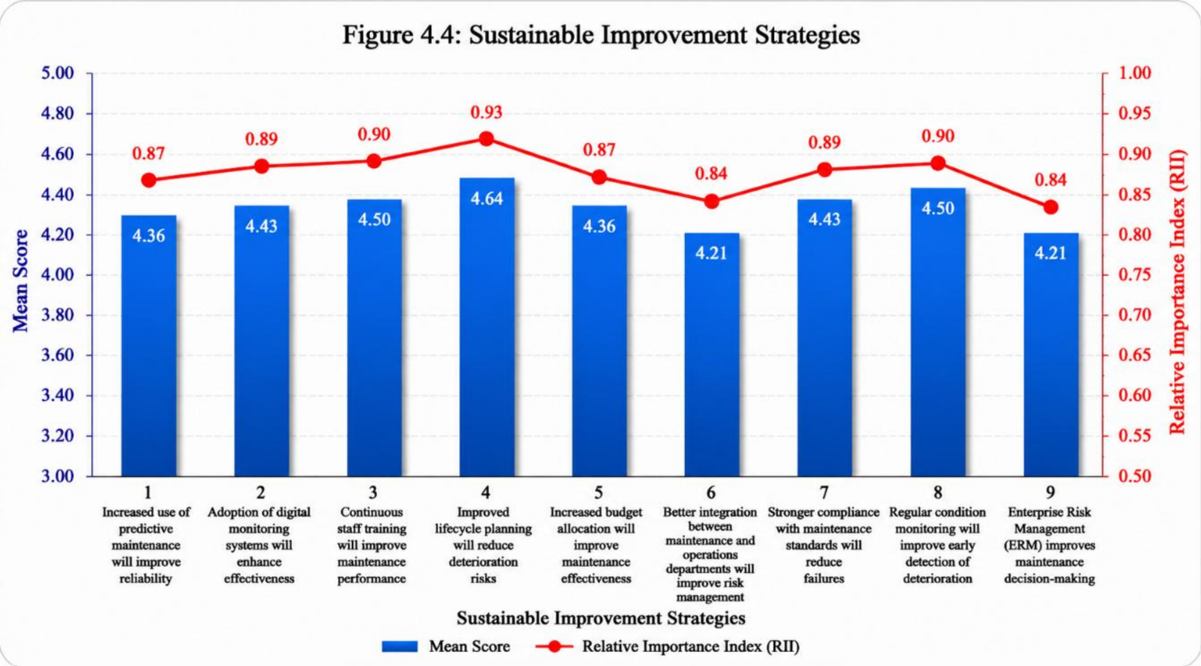


The findings indicate that ageing infrastructure, inadequate funding, shortage of skilled personnel, and operational pressure leading to deferred maintenance are the major challenges affecting effective implementation of risk management practices at NLNG.

Sustainable Approaches for Improving Risk Management Practices

Table 10: Sustainable Improvement Strategies

S/N	Variables	Mean Score	RII	Rank
1	Increased use of predictive maintenance will improve reliability	4.36	0.87	5
2	Adoption of digital monitoring systems will enhance effectiveness	4.43	0.89	3
3	Continuous staff training will improve maintenance performance	4.5	0.9	2
4	Improved lifecycle planning will reduce deterioration risks	4.64	0.93	1
5	Increased budget allocation will improve maintenance effectiveness	4.36	0.87	5
6	Better integration between maintenance and operations departments will improve risk management	4.21	0.84	7
7	Stronger compliance with maintenance standards will reduce failures	4.43	0.89	3
8	Regular condition monitoring will improve early detection of deterioration	4.5	0.9	2
9	Enterprise Risk Management (ERM) improves maintenance decision-making	4.21	0.84	7



The findings reveal that lifecycle planning, staff training, condition monitoring, predictive maintenance, and digital monitoring systems are major sustainable approaches for improving risk management practices in civil infrastructure maintenance at NLNG.

Qualitative Analysis of Open-Ended Responses

The qualitative responses obtained from respondents revealed recurring themes relating to major infrastructure risks, implementation challenges, and sustainable improvement strategies affecting civil infrastructure maintenance at NLNG. The responses were grouped and summarized based on similarities in opinions and practical experiences of respondents.

Major Risks Identified

Respondents identified corrosion of reinforced concrete and steel structures, environmental degradation arising from marine exposure, and ageing infrastructure as the most critical risks affecting civil infrastructure maintenance at NLNG. Respondents further emphasized that the harsh coastal environment of Bonny Island, characterized by humidity, chloride attack, and saline conditions, significantly accelerates infrastructure deterioration and increases maintenance complexity. Operational pressures leading to deferred maintenance, inadequate monitoring technologies, shortage of skilled manpower, and overloading of infrastructure assets were also identified as major contributors to increased infrastructure risk exposure.

Key Challenges Identified

The respondents revealed that inadequate maintenance funding, poor coordination among departments, insufficient training and competency development, and operational pressures resulting in limited maintenance windows are major challenges affecting the effectiveness of risk management practices at NLNG. Respondents also noted that inadequate risk assessment systems, limited adoption of digital monitoring technologies, and organizational bottlenecks reduce the efficiency of maintenance planning and execution. These findings indicate that financial, operational, organizational, and technological constraints significantly affect effective infrastructure risk management implementation.

Suggested Improvement Strategies

Respondents recommended the adoption of predictive and risk-based maintenance systems, increased deployment of digital monitoring technologies, and improved lifecycle planning as sustainable approaches for improving infrastructure maintenance performance at NLNG. Continuous workforce training, better integration between maintenance and operations teams, increased maintenance budget allocation, and improved inspection and structural monitoring systems were also identified as essential strategies for enhancing infrastructure reliability, reducing maintenance risks, and ensuring sustainable plant operations.

Test of Hypotheses

The hypotheses were tested using Spearman Rank Correlation coefficient at 0.05 level of significance.

Hypothesis One (H_{01})

Identified risk types do not significantly affect civil infrastructure maintenance performance at NLNG.

Table 11: Spearman Rank Correlation for Hypothesis One

Variables	Spearman's rho (r_s)	p-value	Decision
Risk Types and Maintenance Performance	0.764	0.007	Reject H01

Since the p-value of 0.007 is less than 0.05, the null hypothesis was rejected. Therefore, identified risk types significantly affect civil infrastructure maintenance performance at NLNG.

Hypothesis Two (H_{02})

There is no significant relationship between identified risk types and risk management styles adopted in civil infrastructure maintenance at NLNG.

Table 12: Spearman Rank Correlation for Hypothesis two

Variables	Spearman's rho (r_s)	p-value	Decision
Risk Types and Risk Management Styles	0.711	0.012	Reject H02

Since the p-value of 0.012 is less than 0.05, the null hypothesis was rejected. Therefore, there is a significant relationship between identified risk types and risk management styles adopted in civil infrastructure maintenance.

Hypothesis Three (H_{03})

Implementation challenges do not significantly affect the effectiveness of risk management practices in civil infrastructure maintenance at NLNG.

Table 13: Spearman Rank Correlation for Hypothesis Three

Variables	Spearman's rho (r_s)	p-value	Decision
Implementation Challenges and Risk Management Effectiveness	0.682	0.018	Reject H03

Since the p-value of 0.018 is less than 0.05, the null hypothesis was rejected. Therefore, implementation challenges significantly affect the effectiveness of risk management practices in civil infrastructure maintenance.

Hypothesis Four (H_{04})

Sustainable risk management practices do not significantly enhance infrastructure reliability, safety performance, and sustainable plant operations at NLNG.

Table 14: Spearman Rank Correlation for Hypothesis Four

Variables	Spearman's rho (r_s)	p-value	Decision
Sustainable Practices and Maintenance Effectiveness	0.824	0.003	Reject H04

Since the p-value of 0.003 is less than 0.05, the null hypothesis was rejected. Therefore, sustainable risk management practices significantly enhance infrastructure reliability, safety performance, and sustainable plant operations at NLNG.

Discussion of Findings

Discussion of Findings for Hypothesis One

The findings revealed that corrosion, environmental exposure, marine conditions, and ageing infrastructure significantly affect civil infrastructure maintenance performance at NLNG. The aggressive coastal and marine environment of Bonny Island accelerates deterioration of steel and reinforced concrete structures, thereby increasing maintenance risks and operational challenges. The finding supports the studies of Frangopol et al. (2004) and Nguyen et al. (2022), who identified environmental exposure and infrastructure ageing as major causes of infrastructure deterioration.

Discussion of Findings for Hypothesis Two

The study found that routine inspections, preventive maintenance, risk assessments, Reliability-Centered Maintenance (RCM), and Risk-Based Maintenance (RBM) are widely adopted risk management styles in civil infrastructure maintenance at NLNG. The findings indicate that the organization applies structured maintenance systems aimed at improving infrastructure reliability and reducing operational risks. However, the relatively low ranking of digital technologies suggests that digital transformation in infrastructure monitoring is still developing.

Discussion of Findings for Hypothesis Three

The findings established that ageing infrastructure, inadequate funding, shortage of skilled personnel, poor communication, and operational pressure significantly affect the implementation of risk management practices at NLNG. Respondents indicated that operational demand and production pressure often result in deferred maintenance activities, thereby increasing infrastructure vulnerability and risk exposure.

Discussion of Findings for Hypothesis Four

The study revealed that predictive maintenance, digital monitoring systems, lifecycle planning, condition monitoring, and continuous staff training significantly improve infrastructure reliability and maintenance effectiveness. The findings suggest that sustainable infrastructure maintenance requires proactive and technology driven maintenance strategies supported by competent personnel, effective coordination, and adequate maintenance funding.

Summary of findings, Conclusion and Recommendations.

Summary of Findings

The study examined the risk management practices, challenges, and prospects in civil infrastructure maintenance at Nigeria LNG Limited with emphasis on identifying major infrastructure risks, examining risk management styles, evaluating implementation challenges, and proposing sustainable improvement strategies.

The findings revealed that civil infrastructure maintenance at NLNG is significantly affected by environmental exposure, corrosion of reinforced concrete and steel structures, marine and coastal conditions, ageing infrastructure, and operational pressures. Corrosion and environmental degradation were identified as the most critical risks affecting infrastructure performance due to the harsh coastal and marine environment of Bonny Island.

The study further established that several structured risk management styles are currently adopted within NLNG civil infrastructure maintenance operations. These include routine inspections, preventive maintenance, risk assessments, Reliability Centered Maintenance (RCM), Risk Based Maintenance (RBM), and alignment of maintenance activities with organizational safety objectives. However, the integration of digital monitoring technologies and predictive maintenance systems remains relatively limited compared to other maintenance practices.

The findings also revealed that ageing infrastructure, inadequate maintenance funding, shortage of skilled personnel, operational pressures leading to deferred maintenance, inadequate technological systems, and poor coordination among departments are major challenges affecting the effectiveness of risk management practices in civil infrastructure maintenance.

Furthermore, the study established that sustainable approaches such as predictive maintenance, lifecycle planning, regular condition monitoring, deployment of digital monitoring systems, staff training, stronger compliance with maintenance standards, and better integration between maintenance and operations departments significantly improve infrastructure reliability, maintenance effectiveness, and sustainable plant operations.

The hypotheses testing using Spearman Rank Correlation revealed that:

i. Identified risk types significantly affect civil infrastructure maintenance performance at NLNG.
ii. There is a significant relationship between identified risk types and risk management styles adopted in civil infrastructure maintenance.
iii. Implementation challenges significantly affect the effectiveness of risk management practices in civil infrastructure maintenance.
iv. Sustainable risk management practices significantly enhance infrastructure reliability, safety performance, and sustainable plant operations at NLNG.

The qualitative findings further reinforced the quantitative results by emphasizing that corrosion, ageing infrastructure, inadequate maintenance resources, limited digital systems, and insufficient competency development are major concerns affecting infrastructure maintenance effectiveness at NLNG.

Conclusion

This study concludes that risk management plays a critical role in ensuring the reliability, safety and sustainability of civil infrastructure maintenance within LNG operations. The findings demonstrate that civil infrastructure assets at NLNG are increasingly exposed to deterioration risks associated with ageing infrastructure, harsh environmental conditions, marine exposure, and operational demands.

The study further concludes that although structured maintenance approaches such as preventive maintenance, RCM, RBM, and routine inspections are already implemented within NLNG, several operational and organizational challenges continue to limit the full effectiveness of these systems. Inadequate digital integration, shortage of skilled personnel, insufficient maintenance funding, and operational pressures significantly reduce the efficiency of infrastructure risk management practices.

The study also concludes that sustainable infrastructure maintenance within LNG facilities requires a proactive, technology driven and lifecycle-based maintenance strategy supported by competent personnel, adequate funding, effective coordination, and continuous improvement systems. The adoption of predictive maintenance technologies, digital monitoring systems, and integrated risk management frameworks is essential for improving infrastructure reliability and reducing long term maintenance risks within ageing LNG facilities.

Overall, the study establishes that improving risk management practices in civil infrastructure maintenance is essential for enhancing asset integrity, operational continuity, safety performance, environmental sustainability, and long-term infrastructure reliability at NLNG.

Recommendations

Based on the findings of this study, the following recommendations are made:

i. NLNG should strengthen the implementation of predictive, preventive, and risk-based maintenance strategies supported by regular inspections, condition monitoring and prioritization of critical infrastructure assets based on risk exposure, asset condition and safety implications to reduce infrastructure deterioration and unexpected failures.
ii. The organization should increase the deployment of digital monitoring technologies such as structural health monitoring systems, corrosion monitoring tools, and digital asset management platforms while also strengthening Enterprise Risk Management (ERM) frameworks to improve infrastructure risk assessment, maintenance planning, and decision-making processes.
iii. Management should improve lifecycle planning, long term infrastructure renewal strategies, and maintenance funding to support timely maintenance interventions, rehabilitation works, and sustainable management of ageing civil infrastructure assets exposed to harsh marine and coastal environmental conditions.
iv. Continuous training and competency development programmes should be organized for maintenance personnel to improve technical capability, risk management knowledge and effective utilization of modern maintenance technologies and systems.
v. Better coordination, communication and integration should be established among maintenance, operations, engineering, and planning departments to improve maintenance efficiency, reduce operational delays, and support effective implementation of infrastructure risk management practices.

Contribution to Knowledge

This study contributes to knowledge in several important ways.

First, the study provides empirical evidence on the specific types of risks affecting civil infrastructure maintenance within an operational LNG facility in Nigeria, particularly within the coastal and marine environment of Bonny Island. This contributes to the limited body of literature on infrastructure risk management within operational LNG plants.

Second, the study expands existing knowledge on the application of structured risk management styles such as Reliability Centered Maintenance (RCM), Risk Based Maintenance (RBM), preventive maintenance, predictive maintenance, and Enterprise Risk Management (ERM) within civil infrastructure maintenance systems.

Third, the study identifies and empirically validates major implementation challenges affecting infrastructure risk management practices in LNG facilities, including ageing infrastructure, inadequate funding, shortage of skilled personnel, technological limitations, and operational pressures.

Fourth, the study provides practical and sustainable improvement strategies for enhancing infrastructure reliability, safety performance, and maintenance effectiveness through lifecycle planning, predictive maintenance, digital monitoring systems, and competency development.

Finally, the study contributes to the growing discourse on sustainable infrastructure maintenance and asset lifecycle management within the Nigerian oil and gas industry by bridging the gap between theoretical risk management frameworks and practical implementation within high-risk industrial environments.

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