Int. j. adv. multidisc. res. stud. 2024; 4(6):3313-3334

Received: 10-11-2024
Accepted: 20-12-2024

International Journal of Advanced Multidisciplinary Research and Studies

ISSN: 2583-049X

Recent Advances in Preservation and Functional Integrity of Offshore Mooring Packages During Extended Standby

[1] **Henry Chukwuemeka Olisakwe,** [2] **Nwakamma Ninduwezuor-Ehiobu,** [3] **Paul Chibuike Obetta**
[1] Department of Mechanical Engineering, Nnamdi Azikiwe University Awka, Anambra State, Nigeria
[2] FieldCore Canada, A GE Vernova Company, United States of America
[3] STIS Nigeria Ltd for TotalEnergies, Nigeria

Corresponding Author: **Henry Chukwuemeka Olisakwe**

Abstract
Offshore mooring packages, comprising chain, wire rope, synthetic fiber rope, connectors, anchors, tensioners, buoyancy modules, and associated handling equipment, are increasingly subjected to extended standby periods before deployment or between service campaigns. Drivers include the serialization demands of floating offshore wind (FOW), supply chain lead times for large diameter chain and forged connectors, project schedule slippage, and the growing practice of pre-laying and wet storing mooring lines ahead of floater arrival. Standby, whether onshore in laydown yards, quayside, or subsea in wet storage, exposes mooring components to degradation mechanisms that differ materially from in-service conditions: Atmospheric and splash zone corrosion, microbiologically influenced corrosion (MIC) in stagnant seabed conditions, ultraviolet (UV) and creep effects in synthetic ropes, marine growth on connectors and quick-connect interfaces, and loss of certification currency. This paper reviews advances reported through 2024 in preservation technologies, integrity assessment methods, monitoring systems, and standards development relevant to extended standby of mooring packages. Key developments include retrofit cathodic protection systems for chain, improved coating and thermally sprayed aluminum practice, vapor phase corrosion inhibitor (VCI) packaging for connectors and machined interfaces, industry joint programs on wet storage and quick connectors, reliability based inspection planning, and digital integrity management frameworks extending to the pre-service phase. Gaps are identified in standardized wet storage duration limits, synthetic rope requalification after storage, and traceability of preservation history through the supply chain. Recommendations are offered for a preservation centered mooring integrity management (MIM) approach that treats standby as a managed life cycle phase rather than an idle interval.

Keywords: Mooring Systems, Preservation, Wet Storage, Floating Offshore Wind, Corrosion Protection, Integrity Management, Extended Standby, Cathodic Protection, Synthetic Rope

1. Introduction

1.1 Background

Mooring systems represent a critical and costly element of floating offshore infrastructure. For floating production storage and offloading (FPSO) units, tension leg platforms, semi-submersibles, and floating offshore wind turbines (FOWTs), station keeping depends on the sustained structural integrity of chains, ropes, connectors, and anchors that must perform reliably for 20 to 30 years in aggressive marine environments. Industry data from floating wind projects indicate that mooring systems can constitute on the order of 20 percent of total project investment, and mooring component failures remain among the most consequential integrity events in floating asset operation.

Historically, mooring integrity research has concentrated on the in-service phase (COREWIND, 2020): Fatigue of chain links under cyclic loading, corrosion and wear in the splash zone and thrash zone, and inspection of aged systems for life extension. However, a distinct and growing challenge has emerged in the pre-service and inter-service phases. Mooring packages are now routinely manufactured, delivered, and then held in standby for months or years before hook-up. This standby can take several forms:

1. **Onshore laydown storage** of chain, connectors, and anchors at mobilization ports, often in coastal atmospheres with high chloride deposition.
2. **Quayside and covered storage** of synthetic rope on reels or drums, winches, tensioners, and instrumented components.
3. **Subsea wet storage**, in which mooring lines and anchors are pre-installed and laid on the seabed, buoyed off, and left in a dormant tensioned or slack condition awaiting floater arrival.
4. **Inshore temporary moorings** used for wet storage of floating substructures awaiting turbine integration, which themselves require dedicated pre-laid mooring spreads.

Each of these regimes imposes degradation mechanisms and integrity risks that conventional design codes, written around the in-service condition, address only partially. The rapid scale-up of floating offshore wind between 2020 and 2024, with multi-line pre-lay campaigns of over one hundred mooring lines per wind farm, has made standby preservation a first-order commercial and technical issue. The problem is also inseparable from the supply chain: Risk management frameworks developed for EPC and gas processing projects (Agbabiaka *et al*., 2019) and resilience frameworks for critical energy infrastructure (Ogunwole *et al*., 2021) demonstrate that long-lead, high-value equipment held between manufacture and installation constitutes a distinct risk category requiring deliberate governance rather than passive warehousing. Foundational work on strategic procurement optimization in oil and gas operations (Okonkwo *et al*., 2018a), inventory availability and plant uptime improvement in energy facilities (Okonkwo *et al*., 2018b), and cost reduction through contract negotiation and vendor governance (Okonkwo *et al*., 2019) established the link between disciplined materials management and asset availability that standby preservation now extends offshore.

1.2 Objectives and Scope

This paper reviews recent advances, with emphasis on developments reported in and around 2024, in four areas:

- Preservation technologies for mooring hardware during onshore and subsea standby.
- Assessment of functional integrity, including degradation modeling and requalification.
- Monitoring, inspection, and digital integrity management applied to the standby phase.
- Standards, joint industry programs (JIPs), and regulatory context.

The scope covers complete mooring packages: Chain (studless and studded), steel wire rope, synthetic fiber rope (polyester, nylon, and high modulus polyethylene, HMPE), connectors (shackles, H-links, tri-plates, quick connectors), anchors (drag embedment, suction piles, plate anchors), tensioning and hang-off hardware, buoyancy elements, and load monitoring instrumentation.

1.3 Review Methodology

This paper is a structured narrative review. Source material was drawn from four streams: Peer reviewed journal literature on mooring reliability, corrosion, fatigue, and installation logistics; joint industry programme and industry association publications, including floating wind JIP outputs and mooring integrity white papers; standards activity and classification society practice, including code check case studies and the ISO 25249 proposal; and vendor and contractor technical literature describing commercially available preservation, protection, and monitoring products through 2024. In addition, a body of conceptual and applied research from adjacent industrial domains, spanning procurement and supply chain governance, occupational safety, non-destructive testing, condition monitoring, energy systems, and digital compliance, was screened for transferable frameworks, on the reasoning that standby preservation is as much a logistics, safety, and governance problem as a materials problem.

Inclusion required that a source either address mooring hardware directly, address a degradation or preservation mechanism active during standby, or supply a decision, governance, or monitoring framework demonstrably transferable to the standby phase. Sources published after 2024 were excluded to keep the review anchored to its stated period. The material was synthesized thematically rather than statistically: No meta-analysis was attempted, because the underlying studies are heterogeneous in method and scope and because much of the most operationally relevant material, such as JIP findings and vendor qualification data, is not reported in a form amenable to quantitative pooling. The synthesis was organized around four questions. What degrades, and how fast, in each standby regime? What preservation technologies and practices demonstrably slow that degradation? How can the resulting condition be assessed, monitored, and carried into service records? And what standards, contracts, and organizational arrangements are needed to make the first three answers routine rather than exceptional? Sections 2 through 9 follow that structure, with economics, risk, case perspectives, and human factors treated in dedicated sections because they cut across all four questions. Limitations of the method are discussed in Section 11.

1.4 Terminology

Several terms are used throughout with specific meanings. *Standby* denotes any interval in which manufactured mooring hardware is not performing its station keeping function, whether before first installation or between service campaigns. *Preservation* denotes the deliberate measures taken to arrest or slow degradation during standby, together with the records that evidence those measures. *Wet storage* denotes subsea standby, typically pre-laid lines and anchors on or in the seabed, buoyed off pending connection. *Requalification* denotes the process by which a component emerging from standby is demonstrated fit to enter or re-enter service under its original or amended certification. *Mooring integrity management* (MIM) denotes the lifecycle process, spanning design, manufacture, installation, operation, and here explicitly standby, through which fitness for service is assured and evidenced. *Mobilization* denotes the transition out of standby: Retrieval or receipt of hardware, requalification, load-out, and hook-up. Finally, the *preservation dossier* or *integrity dossier* denotes the component-resolved record set, initiated at manufacture and maintained through standby, on which documentation-based requalification depends. These definitions matter because much of the ambiguity in current practice traces to terms being used loosely across contracts: A supply contract that ends at "delivery," a storage contract that begins at "receipt," and an installation contract that begins at "handover" can, without these definitions pinned to preservation state, jointly leave the standby phase formally owned by no one.

2. Degradation Mechanisms During Extended Standby

2.1 Onshore and Atmospheric Storage

Mooring chain and forged connectors stored in coastal laydown yards experience atmospheric corrosion accelerated by salt aerosol, humidity cycling, and standing water in link crowns and connector bores. Reviews of corrosion risk assessment for industrial process equipment confirm that the exposure environment drives degradation rates that vary strongly by microenvironment and that mitigation must be matched to the specific exposure regime rather than applied generically (Atta *et al*., 2020). Uncoated chain relies on a generous corrosion allowance, but non-uniform pitting during storage consumes allowance intended for service life and can create initiation sites for fatigue cracking. Storage-phase handling itself is a hazard: Risk pathway models for lifting and rigging in heavy industrial construction (Arumosoye and Obriki, 2022) and risk management models for heavy lifting and crane installation operations (Obogo *et al*., 2020b) apply directly to the repeated craneage, spooling, and repositioning that chain, anchors, and reels undergo in laydown yards, where dropped-object and impact damage can silently compromise components long before mobilization. Machined and proof-load-tested interfaces, such as connector pins, locking mechanisms, and quick connector mating faces, are especially sensitive: Even modest pitting or fretting damage in storage can compromise assembly tolerances, sealing, and load transfer.

Synthetic fiber ropes face a different threat profile. Polyester and HMPE ropes are vulnerable to UV degradation of jackets and exposed yarns, ingress of grit and particulate that later causes internal abrasion under load, rodent and handling damage, and, for nylon, moisture-related property changes. Storage on undersized drums can impose bend set and residual twist. Creep-prone materials such as earlier generation HMPE require attention to how ropes are tensioned or restrained on reels. Improved creep resistance from newer HMPE formulations, which by 2024 enabled rope lengths exceeding 3 km for deepwater floating wind, has reduced but not eliminated storage-phase creep concerns.

Mechanical and electro-hydraulic equipment in the package, including winches, chain jacks, tensioners, and load cells, degrades through seal deterioration, lubricant separation, internal condensation, and electrical connector corrosion when idle. Loss of function is frequently discovered only at mobilization, when rectification is most expensive.

2.2 Subsea Wet Storage

Pre-laid mooring lines wet stored on the seabed are exposed to conditions that differ from the design in-service profile in several important respects:

- **Stagnant, sediment-rich environment:** Lines lying in or on soft sediment experience low oxygen but potentially aggressive microbiologically influenced corrosion, particularly from sulfate reducing bacteria in anaerobic mud. Localized MIC rates can substantially exceed the uniform corrosion rates assumed in design codes for catenary touchdown zones.
- **Absence of cathodic protection:** In-service moorings connected to a protected floater may receive partial cathodic protection near the fairlead; wet stored lines are typically electrically isolated and unprotected unless dedicated anodes are fitted.
- **Marine growth and calcareous fouling:** Connectors, quick connect interfaces, buoy hardware, and pick-up arrangements accumulate hard and soft fouling that impedes later mating, inspection, and ROV intervention. Industry joint programme findings through 2024 (Carbon Trust, 2024) explicitly identify corrosion of connectors and marine growth on mechanical components as principal added risks when connection assemblies are submerged for wet storage.
- **Trenching, embedment, and mechanical damage:** Ground chain sections can self-bury; lines can be disturbed by fishing interaction, dropped objects, or mobile sediments, and dormant lines are subject to slow cyclic motion from currents that can cause localized wear at touchdown and buoy interfaces.
- **Uncertain duration:** Weather-window driven installation logistics mean the interval between pre-lay and hook-up is stochastic. Planning studies of multi-campaign pre-lay operations for floating wind farms demonstrate that bottom chains and drag anchors are deliberately pre-installed and wet stored as a core installation strategy, making standby duration a designed, but variable, parameter. Improved metocean and renewable forecasting, including hybrid deep learning models for wind power prediction (Komi, 2021), can narrow this uncertainty by sharpening weather window planning for hook-up campaigns.

These subsea standby exposures are best treated within a lifecycle risk framing. Conceptual frameworks for lifecycle risk assessment in offshore environmental management (Falegan and Aniebonam, 2022) illustrate the value of assessing offshore assets across all phases of their existence, including dormant intervals, rather than only during active operation, and this framing transfers naturally to wet stored mooring hardware. Companion reviews of integrated treatment strategies for demanding environments (Falegan and Aniebonam, 2023) and of decentralized treatment systems for remote energy assets (Falegan and Aniebonam, 2024) reinforce the same lifecycle and data-centric orientation now being applied to dormant mooring assets.

2.3 Certification and Documentation Decay

Beyond physical degradation, mooring packages in extended standby suffer administrative integrity loss. Class and certification bodies impose validity windows on proof load tests, non-destructive examination (NDE) records, and rope certificates. When storage exceeds these windows, requalification is required, but until recently there was little standardized guidance on what re-testing regime is proportionate for components that have been properly preserved. This gap has been a focus of industry attention in the 2023 to 2024 period.

2.4 Component-Specific Degradation Profiles

The generic mechanisms above land differently on each element of the mooring package. A preservation plan that treats the package as a single commodity will over-protect some components and, more dangerously, under-protect others. This subsection profiles the principal component classes.

Chain: Studless and studded chain in R3 to R5 grades is the most forgiving component in storage because it is designed with corrosion allowance and has no machined sealing surfaces. Its vulnerabilities are nevertheless real: Pitting concentrated at inter-link contact points and in the crown radius, where fatigue stresses later concentrate; pack rust between stacked links that traps chloride-laden moisture; and, for wet stored ground chain, microbiologically influenced attack in anaerobic sediment that can localize metal loss far beyond the uniform rate assumed in design. Grade sensitivity matters as well: Higher strength grades are more susceptible to hydrogen related mechanisms, so any storage-phase cathodic protection must respect potential limits, a point long established for tensioned high strength elements protected by thermally sprayed aluminum. Handling damage, gouges from grabs and forks, and bar-on-bar impact during spooling are the other storage-phase entries in the chain damage ledger (Arumosoye and Obriki, 2022; Obogo *et al*., 2020b).

Steel wire rope: Spiral strand and six strand wire rope depends for its service life on the integrity of its blocking compound and, where fitted, its sheathing. In storage, ultraviolet exposure embrittles polymer sheathing, compound migrates and drains from vertically stored reels, and moisture ingress at terminations initiates internal corrosion that is invisible to external inspection. Wire rope stored on undersized reels takes a set that elevates bending stresses in early service. Because internal condition cannot be verified visually, wire rope requalification after long storage leans heavily on the NDT toolbox, including electromagnetic methods, an area where the general NDT integrity assessment literature (Atta *et al*., 2020; Atta *et al*., 2021) transfers directly.

Polyester rope: Polyester is chemically stable in seawater and tolerant of long submersion, which is why it dominates deepwater taut moorings, but its storage sensitivities are mechanical and particulate. Jacket damage during handling opens paths for grit ingress, and internal abrasion by ingested particles is a leading cause of strength loss in service. Bend set from small reels, twist introduced during spooling, and crushing of lower layers under reel self-weight all degrade the load sharing among sub-ropes on which the rope's rated strength depends. Ultraviolet degradation affects exposed jackets and any yarns visible at splices. Storage specification therefore centers on jacket integrity verification, opaque wrapping, controlled reel geometry, and cleanliness.

HMPE rope: High modulus polyethylene shares the particulate and handling sensitivities of polyester and adds creep as a storage consideration: Earlier generation HMPE under sustained tension elongates permanently, so reel tension and any suspended storage configuration must be controlled. Newer formulations with improved creep resistance, which by 2024 supported rope lengths beyond 3 km for deepwater floating wind, have relaxed but not removed this constraint. HMPE is also more temperature sensitive than polyester, arguing for shaded or covered storage in hot climates, a consideration that connects to the heat management literature for industrial operations in extreme environments (Arumosoye and Obriki, 2018).

Connectors and quick connectors: Shackles, H-links, tri-plates, and tensioner interfaces concentrate the package's machined surfaces, threads, and securing hardware, and they are the components most often found unfit at mobilization. Pitting of a pin seat, corrosion binding of a nut, or fretting at a bearing face can each render a certified connector unusable without extensive rework. Quick connectors intended for subsea dormancy add elastomer seals, latching mechanisms, and in some designs electrical continuity paths, all of which are sensitive to marine growth and crevice corrosion when submerged, exactly the risks the wet storage JIP work identifies. Preservation for this class is correspondingly the most intensive: Sealed enclosures, inhibitor environments, exercise schedules, and protective caps and shrouds subsea.

Anchors: Drag embedment anchors, suction piles, and plate anchors are robust weldments whose storage risks are weld zone corrosion, coating breakdown at handling contact points, and deformation from improper stacking or lifting. Suction piles add internal coating condition and the serviceability of vent and pump interfaces. For pre-installed anchors on the seabed, the dominant standby questions are holding capacity evolution as soils consolidate or scour, and the condition of padeyes and connection interfaces that must later accept load, both of which are survey items rather than preservation items. Weld quality assurance practice from large fabrication programs (Atta *et al*., 2022) governs both the baseline condition record and any storage-phase repair.

Buoyancy modules and pick-up arrangements: Syntactic foam and polyethylene buoyancy units degrade through ultraviolet exposure, water absorption at damaged skins, and clamp hardware corrosion. Pick-up lines, pendants, and surface buoys used to buoy off wet stored lines are working equipment throughout the standby period and weather, chafe, and fatigue accordingly; several recorded wet storage incidents in adjacent marine sectors trace to pick-up gear rather than the stored asset itself. These items therefore need in-service style inspection intervals even while the main package is dormant, a vigilance pattern for low-activity periods that the continuous hazard monitoring literature describes (Obriki *et al*., 2023a).

Instrumentation and electro-hydraulic equipment: Load cells, inclinometers, data loggers, winches, and chain jacks combine electronics, seals, and fluids, each with its own shelf life. Battery chemistry degradation during storage, seal compression set, lubricant separation, and connector pin corrosion are the recurring findings at mobilization function tests. The battery degradation literature for demanding thermal environments (Komi and Ganiu, 2022) and the predictive maintenance transition literature (Sunday *et al*., 2020) frame the two halves of the answer: Manage the storage environment, and verify function on a schedule rather than at the point of need.

2.5 Interaction and Sequencing Effects

Degradation mechanisms during standby rarely act alone, and three interaction patterns deserve explicit recognition because they defeat single-mechanism thinking.

The first is sequence dependence between storage and service damage. Storage-phase pitting is not merely lost corrosion allowance; a pit at a fatigue-critical location acts as an initiation site whose in-service consequence is disproportionate to the metal lost. The fatigue reliability literature makes clear that surface condition entering service shifts the whole life distribution, which is why the requalification pathways of Section 4.4 grade surface condition against fatigue relevance rather than treating all metal loss equally. Similarly, particulate ingested by a rope in the yard does its damage later, under cyclic load, in a location no post-storage inspection will see.

The second is protection interaction. Measures that solve one mechanism can feed another if applied without system thinking. Impermeable wrapping applied over damp hardware creates a poultice that accelerates the corrosion it was meant to prevent; over-polarized cathodic protection on high strength chain trades corrosion for hydrogen embrittlement risk; heavy grease on a connector traps abrasive grit against the very surfaces it protects; and marine growth on a wet stored quick connector may slow general corrosion beneath it while blocking the mechanism the connector exists to perform. A preservation specification is therefore reviewed as a system, with each measure checked against every mechanism in the component's profile, not only the one that motivated it.

The third is administrative and physical coupling. Certificate expiry and physical degradation run on independent clocks, and the binding constraint flips between them depending on component class and storage quality: Well-preserved chain typically hits documentation limits first, while unpreserved connectors hit physical limits long before their paperwork lapses. Standby planning that tracks only one clock will be surprised by the other, which is the practical reason Section 8.2 recommends managing permit expiries, certificate validity, and physical condition in a single dossier. The sequencing insight generalizes: Standby is not a pause in the component's life history but a chapter of it, and every mechanism catalogued in this section writes into the same cumulative damage account that service will continue.

3. Advances in Preservation Technologies

3.1 Retrofit Cathodic Protection for Chain

A notable 2024 development is the commercialization of clamp-based retrofit cathodic protection for mooring chain. Systems combining a mechanical clamp with a bracket-mounted integrated sacrificial anode allow discrete anode stations to be attached to chain segments, including wet stored ground chain, without hot work or electrical continuity modification of the line. Developed initially for FPSO mooring chains, the technology is explicitly positioned as adaptable to floating wind and aquaculture moorings. Vendors now offer the capability as an integrated package including computer modeling of protection potential distribution along the chain, laboratory and field testing, installation, and verification (Imenco, 2024).

Two implications are significant for standby preservation. First, wet stored lines can be actively protected from the day of pre-lay, arresting both general corrosion and MIC-type localized attack during dormancy. Second, effective cathodic protection of chain opens the possibility of reducing corrosion allowances in new designs, with resulting reductions in chain weight, handling equipment demand, and installation carbon footprint. This aligns with the broader movement toward green procurement strategies that balance cost efficiency with long-term environmental responsibility (Akin-Oluyomi *et al*., 2023a) and with reviews of sustainable environmental practices embedded within occupational safety management systems, including waste handling discipline in industrial facilities (Obogo *et al*., 2024a). For standby management, the modeling component allows operators to demonstrate quantitatively that a wet stored line has remained within protection criteria for the storage duration, supporting requalification without full retrieval.

3.2 Coatings and Thermally Sprayed Aluminum

Coating practice for mooring and tether elements continues to mature. Thermally sprayed aluminum (TSA), long established for tensioned high strength steel elements because it provides bonded anodic protection at a uniform, low cathodic potential that avoids hydrogen embrittlement while extending fatigue life, has seen renewed attention for connectors, hang-off hardware, and accessible chain segments intended for long pre-service storage. For floating wind, the industry trend through 2024 is toward specifying robust coating systems on connectors and accessories at manufacture, explicitly accounting for a storage phase before service, rather than treating coatings purely as an in-service measure.

In parallel, standards activity accelerated: A proposal for ISO 25249, accepted in 2024 and under committee review (PPG, 2024), is intended to address comprehensive corrosion protection strategies for offshore wind structures, spanning paint systems, cathodic protection, corrosion environment assessment, maintenance strategy, and total service life. Although directed at structures broadly, its life cycle framing, which encompasses pre-service exposure, is directly relevant to mooring package preservation planning.

3.3 Preservation of Connectors, Quick Connectors, and Machined Interfaces

The emergence of quick connector technologies for floating wind mooring and dynamic cable systems has raised the stakes for interface preservation. Quick connectors streamline hook-up and enable planned disconnection for tow-to-port maintenance, and they specifically enable wet storage strategies in which the lower connection assembly remains subsea awaiting the floater. Industry joint programme work on wet storage and quick connectors, reported through 2024, identifies connector corrosion and marine growth during submerged standby as key risks and examines mitigation through material selection, sacrificial claddings, protective caps and shrouds, water-excluding grease systems, and buoyed off configurations that keep sensitive interfaces off the seabed.

Onshore, best practice for connector preservation has consolidated around: Vapor phase corrosion inhibitor (VCI) impregnated wrapping and emitters inside sealed enclosures for machined surfaces; peelable or wax-based temporary coatings for pins and bores; desiccant-managed crates with humidity indicators; and periodic exercise (rotation, re-greasing) of moving elements. Research into corrosion inhibitors for mild steel, including systematic reviews of environmentally benign inhibitor chemistries effective in both acidic and alkaline media (Atta *et al*., 2018), supports the trend toward greener inhibitor formulations in preservation packaging, an increasingly important consideration as ESG requirements extend into storage and marshalling operations. While individually mature, the 2024 advance is their systematic incorporation into mooring package preservation specifications with defined inspection intervals and acceptance criteria, mirroring the preservation regimes long used for subsea production equipment.

3.4 Synthetic Rope Storage and Requalification

For polyester and HMPE ropes, preservation advances focus on packaging and condition assurance: UV-opaque, abrasion resistant reel wrapping; controlled reel core diameters to limit bend set; twist management during spooling; sealed end terminations with desiccant; and storage environment specification (temperature, humidity, separation from ozone sources and chemicals). Improved HMPE formulations with enhanced creep resistance reduce sensitivity to prolonged tension during storage and service.

A persistent gap, highlighted in industry discussion through 2024, is the absence of a standardized, non-destructive requalification protocol for ropes emerging from multi-year storage. Current practice relies on jacket visual inspection, sampling and residual strength break tests of witness segments, and manufacturer concurrence. Research directions include embedded fiber optic strain and temperature sensing along rope cores, and acoustic or stiffness-based signature testing, which would allow condition to be tracked through storage rather than inferred at the end of it.

3.5 Preservation of Mechanical, Hydraulic, and Instrumented Equipment

For winches, tensioners, chain jacks, and monitoring instrumentation, preservation practice has converged with the wider offshore equipment preservation discipline: Long-term preservation fluids and inhibited oils; nitrogen blanketing of hydraulic circuits; heated or dehumidified storage for electronics; battery management plans for autonomous load monitoring nodes; and documented periodic function testing. This mirrors the broader shift in mechanical asset management from reactive to predictive maintenance philosophies (Sunday *et al*., 2020), the sensor-based fault detection approaches proven on building services plant (Sunday and Omoegun, 2022), and the control and efficiency studies showing that idle or part-load operation degrades thermal and mechanical systems differently from rated duty (Sunday *et al*., 2019) and the structured preventive maintenance program designs now applied in renewable energy systems (Yeboah *et al*., 2024), both of which emphasize scheduled condition verification of idle or intermittently used equipment. Preservation regimes are increasingly subject to formal verification as well: Internal QHSE audit systems developed for industrial engineering operations (Obogo *et al*., 2020a) provide the audit architecture through which storage environments, preservation task completion, and record quality can be independently checked at defined intervals. For battery powered monitoring nodes and stored energy storage components, degradation research on batteries in hot and demanding environments (Komi and Ganiu, 2022) underlines the need for temperature managed storage and state-of-charge maintenance plans during long standby. Yard mechanization is a related consideration: Integrated path-planning and slotting optimization models for robot-enabled high-density warehousing (Akanbi and Sunday, 2024) indicate how stock arrangement and retrieval sequencing can be optimized so that preservation access, rather than pure storage density, drives layout in long-duration laydown areas.

Equally important is the logistics dimension: Conceptual models linking materials readiness to maintenance-driven supply chain performance (Okonkwo *et al*., 2021a) capture precisely the failure mode seen at mooring mobilization, where uninspected, unpreserved stock discovered unfit at the point of need drives schedule and cost overruns.

3.6 Yard and Marine Operations Safety During Standby

Preservation is executed by people working around very heavy, awkward hardware, and the standby phase therefore carries its own occupational risk profile. The HSE literature for industrial and energy operations supplies directly transferable models: Integrated heat stress risk frameworks for work in extreme environments (Arumosoye and Obriki, 2018) apply to yard crews handling chain in tropical and desert marshalling locations; systematic use of near-miss and hazard observation data (Arumosoye and Obriki, 2019) and proactive hazard identification using digital safety data streams (Obriki and Arumosoye, 2023) enable early detection of recurring handling risks in storage operations; and continuous hazard monitoring systems (Obriki *et al*., 2023a) extend that vigilance across long, low-activity storage periods when attention naturally decays. Because storage, preservation servicing, and hook-up are typically executed by different contractors, governance-oriented models of contractor safety performance in multi-contract industrial projects (Arumosoye and Obriki, 2020) are especially relevant, as are conceptual models for incident prevention in industrial maintenance environments (Obogo *et al*., 2021b), data-driven occupational safety risk control for large energy infrastructure projects (Obriki and Arumosoye, 2018), and emergency response readiness models for energy and process facilities (Arumosoye and Obriki, 2023), which together frame the safety management system a preservation yard or wet storage campaign should operate under. Depth is available in that literature for each layer of such a system. At the programmatic level, critical reviews of occupational safety management systems in oil and gas maintenance projects (Obogo *et al*., 2020c) and reviews of hazard identification and risk control practice in complex construction settings (Obogo *et al*., 2019c) establish the baseline architecture, while safety governance models for large facility operations (Obogo *et al*., 2022) and construction safety risk governance models for multi-contractor projects (Obogo *et al*., 2019b) address the multi-party structure typical of marshalling yards. At the behavioral level, frameworks explaining the recurrence of unsafe behaviors in high-hazard worksites (Obriki and Arumosoye, 2022), human error causation models for high-risk industrial activity (Obriki and Arumosoye, 2020), and reviews of behavioral safety programs for large workforces (Obriki *et al*., 2023b) explain why routine preservation tasks drift, while workforce safety training models (Obriki *et al*., 2022a) supply the countermeasure. At the leadership and maturity level, organizational learning based maturity models for continuous safety improvement (Arumosoye and Obriki, 2021), safety leadership models for large temporary project organizations (Arumosoye and Obriki, 2024), leadership driven safety culture transformation in large construction workforces (Obogo *et al*., 2019a), and leadership models for safety culture development in engineering projects (Obogo *et al*., 2023) describe how a standby organization sustains discipline over years rather than weeks. Supporting mechanisms include management safety walkthrough frameworks linking observation frequency to culture outcomes (Obriki and Arumosoye, 2019), proactive hazard recognition and near miss reporting systems (Obogo *et al*., 2021a), models for institutionalizing life-preserving practices across project-based organizations (Obriki and Arumosoye, 2021), subcontractor safety performance governance (Obriki and Arumosoye, 2024a), contractor safety compliance systems for infrastructure projects (Obogo *et al*., 2021c), and emergency preparedness and evacuation planning (Obriki *et al*., 2022b) for the storage facilities themselves. The notable trend is contractual: Rental and integrated service models for inshore mooring and wet storage, offered by major mooring contractors for floating wind hull wet storage, bundle equipment preservation, mooring design, pre-lay, and hook-up under a single responsible party, which closes the accountability gaps that historically allowed preservation to lapse between project phases.

3.7 Toward a Preservation Specification Framework

The technologies surveyed above only deliver value when assembled into an enforceable specification. Drawing on the preservation regimes of the subsea production sector and on the materials readiness and audit literature, a standby preservation specification for a mooring package should contain seven elements.

First, a baseline condition record. Every component enters storage with a documented as-received condition: Dimensional checks against certificates, photographic records keyed to unique identifiers, coating condition, and NDT results where the component class warrants them. Without a baseline, later requalification cannot distinguish storage degradation from manufacturing variation, and disputes between supplier, storage contractor, and operator become unresolvable. Welding and fabrication QA records (Atta *et al*., 2022) form part of this baseline for chain and fabricated accessories.

Second, an environmental classification of the storage location. Onshore locations are classified by corrosivity category, temperature and humidity regime, and exposure (open, sheltered, or conditioned); subsea locations by water depth, sediment type, oxygen regime, temperature, current, and biological activity. The classification drives preservation level selection and expected degradation rates, mirroring the exposure-matched mitigation principle established in the corrosion risk assessment literature (Atta *et al*., 2020).

Third, a preservation level assignment per component class. Chain in open storage may need only drainage, segregation from ground contact, and periodic washing; connectors need sealed, inhibited, desiccant-managed enclosures; ropes need controlled reels, opaque covers, and cleanliness control; instruments need conditioned storage and battery management. Wet stored lines are assigned cathodic protection provisions and survey intervals. The assignment is documented as a matrix of component class against storage environment, so that any component can be located in the matrix and its required measures read off unambiguously.

Fourth, a task schedule with defined intervals: Inspections, washdowns, inhibitor renewal, desiccant replacement, mechanical exercise, function tests, CP potential surveys, and marine growth checks, each with a responsible party and a record format. The schedule is the operational heart of the specification, and the materials readiness literature (Okonkwo *et al*., 2021a) makes clear that unscheduled, discovery-based verification is the pattern that produces mobilization failures.

Fifth, acceptance and rejection criteria. Each scheduled task carries pass and fail thresholds: Maximum pit depth against remaining allowance, coating breakdown percentage, seal condition, insulation resistance, CP potential windows, torque and function test limits. Criteria convert inspection into decision and prevent the quiet accumulation of "monitor next time" findings.

Sixth, requalification triggers and scopes. The specification states in advance which events trigger requalification (duration thresholds by component class, environmental excursions, handling incidents, failed scheduled tasks) and what the requalification scope is for each trigger, from documentation review through sample break testing. Pre-agreement removes the negotiation that otherwise delays mobilization.

Seventh, records and audit. All of the above flows into the mooring integrity management dossier initiated at manufacture, and the preservation program itself is subject to periodic independent audit using the internal QHSE audit architectures developed for industrial operations (Obogo *et al*., 2020a), with audit findings tracked to closure. Digital record integrity, including access control and change history, is treated as part of the specification rather than an IT afterthought (Adegbite *et al*., 2022).

A specification with these seven elements converts preservation from a set of good intentions into a contractually enforceable, auditable, and insurable scope of work, which is the practical precondition for everything else this review recommends.

4. Advances in Integrity Assessment and Monitoring

4.1 Reliability-Based Inspection Planning Extended to Standby

Reliability-based inspection (RBI) planning for mooring chains matured substantially in 2024. Published methods construct a continuously updated reliability index for chain segments, fed by inspection results, combining fatigue and corrosion degradation models to schedule future inspections at intervals that maintain a target probability of failure. Parallel work applied both Monte Carlo simulation and first order reliability methods to S-N based fatigue reliability of floating wind mooring chains, with the explicit aim of optimizing inspection strategy and reducing lifetime maintenance cost.

These probabilistic frameworks are underpinned by non-destructive testing (NDT). Critical reviews of NDT-based integrity management and corrosion risk assessment for process equipment (Atta *et al*., 2020) and of NDT methods for weld integrity evaluation in high-capacity infrastructure (Atta *et al*., 2021) provide the inspection toolbox, including ultrasonic, magnetic particle, and radiographic techniques, that feeds chain and connector condition data into reliability updating. Welding inspection standards and quality assurance practice from large-scale power projects (Atta *et al*., 2022) are likewise directly transferable to the manufacture and requalification of flash butt welded chain links and fabricated accessories. More broadly, systematic reviews of incident investigation approaches and prevention-oriented learning in industrial operations (Obriki and Arumosoye, 2024b) show that adjacent industrial sectors are already converting operational and inspection data into forward-looking risk control, a maturity trajectory that mooring standby management can follow.

The advance relevant to standby is conceptual as much as computational: These frameworks accommodate a pre-service degradation increment. Corrosion consumed during wet storage, and any wear at touchdown points during dormancy, can be entered as a prior damage state, so that in-service inspection plans and remaining life assessments start from the true post-standby condition rather than the as-manufactured condition. Reliability analyses consistently identify corrosion rate variability, driven by temperature, flow, oxygen content, marine growth, and microbiological attack, as a dominant uncertainty, reinforcing the value of active preservation (Section 3.1) in narrowing the damage distribution.

4.2 Monitoring During Wet Storage

Monitoring of dormant, pre-laid mooring lines is developing along three lines:

1. **Periodic ROV and survey campaigns**, with photogrammetry and laser scanning to quantify marine growth, trenching and embedment, buoy position, and visible corrosion product, benchmarked against as-laid surveys.
2. **Cathodic protection verification**, using drop cell or ROV-deployed reference electrode surveys where retrofit anodes have been installed, closing the loop on the protection modeling supplied with clamp-anode systems.
3. **Autonomous sensing**, including battery powered inclination, motion, and tension-proxy sensors on buoyed off line ends, and early trials of long-endurance acoustic monitoring to detect line movement or contact events during storage. Sensor-based condition monitoring approaches proven on rotating machinery, such as vibration-based diagnostics implemented on accessible instrumentation platforms (Omoegun *et al*., 2023), are being adapted to stored winches and tensioners, while interpretable machine learning models for early failure prediction in distributed energy assets (Komi and Adamolekun, 2021) point toward analytics that can flag anomalous behavior in dormant, sparsely instrumented mooring hardware without opaque black-box inference. A key enabler for multi-year subsea monitoring is power autonomy: Research on radio frequency energy harvesting for energy autonomous sensing (Asiedu and Quainoo, 2023a), on maintenance free wireless infrastructure built from intermittently powered IoT networks (Asiedu and Quainoo, 2023b), and on the energy, reliability, and latency trade-offs of green communication for next generation IoT (Asiedu and Quainoo, 2024) charts a path toward batteryless or near-batteryless sensor nodes that could survive an entire wet storage campaign without intervention. Machine learning enabled predictive energy management architectures for IoT sensor networks (Kumuyi *et al*., 2024) complement this by optimizing the scarce energy budget of such nodes around the events that matter, such as line movement or contact.

Above the waterline, the survey toolkit matured on infrastructure corridors is directly applicable: Reviews of GIS applications in utility asset management (Dagodzo and Ahiaeke Patrick, 2021a) and integrated UAV, LiDAR, and GIS frameworks for corridor management (Dagodzo and Ahiaeke Patrick, 2021b) map naturally onto laydown yard stock surveys, buoy field inspection, and marshalling port asset mapping, while GIS enabled ERP procurement frameworks (Ahiaeke Patrick *et al*., 2020) allow those spatial records to connect directly to inventory and preservation task systems. The wider UAV literature adds operational specifics: Reviews of UAV applications in transmission line inspection (Dagodzo, 2018b) and frameworks for integrating UAV programs into national inspection regimes (Dagodzo, 2018a) describe the survey planning and data handling disciplines that transfer to periodic stock and buoy field inspection; UAV-based pipeline and corridor monitoring practice (Dagodzo and Ahiaeke Patrick, 2020) and encroachment detection using geospatial methods (Dagodzo and Ahiaeke Patrick, 2022) parallel the problem of detecting third-party interference over wet stored lines; deep learning classification of corridor imagery (Dagodzo *et al*., 2022) suggests automated screening of repeat survey imagery for change; and frameworks for integrating drone operations into enterprise GIS (Dagodzo and Ahiaeke Patrick, 2023a) show how survey outputs become durable asset records rather than isolated inspection reports.

Mooring integrity management (MIM) frameworks articulated for floating wind (World Forum Offshore Wind, 2023) place integrity management at the center of design, manufacturing, installation, and operation, and explicitly anticipate that projects must plan for failure and maintain fitness-for-service evidence over the entire life cycle. The 2024 direction of travel is to instantiate the MIM dossier at the point of manufacture, so that preservation actions, storage environments, and monitoring results during standby form an unbroken digital thread into the operational integrity record.

4.3 Digital Twins and Life Extension Methodologies

Life extension methodologies developed for aged FPSO moorings, combining retrieval, inspection, finite element analysis, and residual break testing of chain to feed system reliability evaluation, provide the template now being adapted to post-storage requalification. Rather than asking whether a 20 year old chain can serve five more years, the same toolset asks whether a chain wet stored for 18 to 36 months retains its full design life, and what inspection scope substantiates that claim. Digital twin implementations extend design-stage mooring models with as-stored condition data, allowing the standby increment of corrosion and wear to be carried through fatigue and strength reassessment automatically. Tiered digital twin architectures developed to bring predictive diagnostics to resource-constrained renewable energy sites (Komi and Adeniji, 2023) offer a pragmatic template for standby monitoring, where full-fidelity twins are rarely economic for dormant hardware. On the records side, conceptual models for asset lifecycle management and inventory visibility (Okonkwo *et al*., 2023) address the traceability gap identified in Section 2.3: Preservation actions, storage locations, and certificate validity can be tracked at component level through an unbroken digital record from factory to hook-up. End-to-end visibility frameworks for transparency, compliance, and traceability across complex global supply chains (Nnabueze *et al*., 2021) extend the same principle upstream, so that a chain segment's provenance, test history, and preservation state remain linked from steel mill through marshalling yard to seabed. Enterprise data governance practice contributes the classification and control layer: Frameworks for data sensitivity classification and regulatory traceability (Aliliele *et al*., 2024a) and for embedding IT risk and ISO compliance controls into digitally transformed supply chains (Mbonu *et al*., 2020a) describe how records that must survive audit, contractor turnover, and jurisdictional change are structured and controlled from the outset.

4.4 Requalification Workflows and Acceptance Pathways

Assessment technology only matters insofar as it feeds a decision, and the decision at the end of standby is acceptance for installation. Practice through 2024 has converged on a tiered requalification workflow with four pathways, selected per component by the risk framework of Section 6.

Pathway A: Documentation acceptance: For components whose preservation records are complete, whose scheduled tasks all passed, and whose storage duration sits within the project's pre-agreed thresholds, requalification is a records review: Certificate validity, baseline versus latest condition record, task completion, and any environmental excursion log. No hardware is touched beyond a receiving visual inspection. This pathway is the payoff of the specification regime in Section 3.7, and its availability is the main economic argument for that regime.

Pathway B: Verification sampling: Where records are complete but the storage duration or environment approaches threshold values, a sampling scope is executed: Dimensional and NDT checks on a defined fraction of chain links and connectors, CP potential verification on wet stored segments, function tests on a sample of mechanical items, and jacket integrity checks with witness break tests on rope samples where storage exceeded rope-specific limits. Sampling fractions are set in advance and escalate only on adverse findings, using the reliability updating logic of Section 4.1 so that each clean result measurably narrows the residual uncertainty (Rezende *et al*., 2024).

Pathway C: Targeted physical requalification: Components with identified barrier failures, handling incidents, or record gaps receive component-specific scopes: Full NDT of implicated chain segments (Atta *et al*., 2020; Atta *et al*., 2021), strip-down inspection of affected connectors, re-termination and proof testing of suspect wire rope, or retrieval and survey of wet stored line sections whose protection could not be verified. The scope is bounded by the incident, not applied to the whole package, which is why incident logging discipline during storage directly controls mobilization cost.

Pathway D: retrieval and destructive verification: The fallback for packages with systematically inadequate records mirrors the FPSO life extension template of Section 7.1: Retrieval sampling, laboratory examination, residual breaking strength testing, and reliability recalculation before a code check. It is thorough, slow, and expensive, and its existence as the default outcome for unpreserved, undocumented packages is the strongest single incentive for everything in Sections 3 and 6.

Two cross-cutting rules complete the workflow. First, acceptance criteria at every pathway reference the same quantities as the design basis, remaining corrosion allowance, minimum breaking load fractions, and fatigue-relevant surface condition, so that requalification outcomes flow directly into updated design calculations rather than parallel paperwork. Second, every pathway outcome, including clean Pathway A acceptances, is written back into the integrity dossier, because today's acceptance record is the baseline for any future storage interval the component may see, including post-disconnection wet storage during tow-to-port maintenance in floating wind operating strategies.

5. Economic and Schedule Dimensions of Standby Preservation

5.1 The Cost Structure of Standby

The direct costs of preservation are modest and visible: Yard space, enclosures and consumables, scheduled labor, anode hardware for wet stored chain, survey campaigns, and the administrative cost of the records regime described in Section 3.7. For a typical floating wind mooring package, these costs amount to a low single digit percentage of package value per year of standby. The costs of not preserving are larger, lumpier, and hidden until mobilization: Replacement of corroded connectors at spot market prices and lead times, retrieval and requalification of wet stored lines whose protection status cannot be demonstrated, sample break testing of ropes with unverifiable storage histories, vessel standby charges while unfit components are rectified, and, in the worst case, hook-up campaign deferral to the next weather season. Because mooring components sit on multi-month to multi-year manufacturing lead times, the replacement path is often not available inside the project schedule at all, which converts a component condition problem into a project delay problem.

5.2 Preservation as Schedule Insurance

The correct economic framing is therefore insurance against schedule loss rather than asset value protection alone. The value at risk is the daily cost of a delayed hook-up spread, the revenue deferral of a late producing or generating asset, and the contractual exposure of missed milestones. Against this, preservation expenditure buys a verified readiness state. Predictive procurement planning models built around sustaining operational uptime (Okonkwo *et al*., 2024b) formalize exactly this trade: Spend steadily and predictably on readiness, or spend episodically and expensively on recovery. Demand forecasting and inventory analytics (Aifuwa *et al*., 2020) sharpen the calculation by predicting which components and consumables the mobilization will actually draw on, so preservation intensity can be weighted toward the critical path items. Inventory availability modeling for energy facilities (Okonkwo *et al*., 2018b) supplies the uptime framing, and cost reduction through contract negotiation and vendor governance (Okonkwo *et al*., 2019) supplies the levers for buying preservation services efficiently.

5.3 Contracting Structures

Three contracting structures dominate current practice. In the first, the operator self-performs preservation with owned yard capacity, retaining full control and full accountability; this suits operators with continuous programs but leaves occasional projects carrying fixed costs. In the second, preservation is embedded in the supply contract, with the manufacturer or an EPC party responsible until handover; this is administratively simple but historically produces the accountability gaps at phase boundaries that this review has repeatedly flagged. In the third, an integrated mooring contractor takes the package under a storage, preservation, and hook-up scope, often with rental components, which aligns incentives because the party responsible for preservation is the party that must later install the hardware. The vendor governance literature (Ahiaeke Patrick *et al*., 2021; Tonoyan *et al*., 2024a) supports structuring any of these with measurable service levels: Preservation task completion rates, audit finding closure times, and mobilization first-pass acceptance rates are all contractible metrics. Regulatory compliant procurement frameworks for high-risk energy environments (Okonkwo *et al*., 2021b) add the compliance overlay where storage jurisdictions impose environmental or customs constraints on long-held project cargo. The project governance literature supplies the surrounding structure: Studies of governance in multinational infrastructure programs (Amayo *et al*., 2023a; Amayo *et al*., 2024b) identify the decision rights, escalation paths, and interface controls that keep a distributed scope coherent, lifecycle project practice for capital facilities (Amayo *et al*., 2024a) illustrates how a lifecycle rather than phase view is contracted, and strategic project management approaches for renewable energy deployment in emerging markets (Amayo *et al*., 2024c) speak to the schedule-driven environments in which floating wind standby decisions are actually made.

5.4 Port Economics and Dwell Time

Finally, standby duration itself is partly an economic variable. Marshalling port congestion, laydown scarcity, and handling bottlenecks lengthen dwell times, and the port logistics literature on demurrage elimination (Okonkwo *et al*., 2020) shows that disciplined flow planning recovers both cost and calendar. Port infrastructure planning for floating wind now explicitly reserves mooring and anchor storage areas and wet storage acreage, and projects that secure classified, serviced storage early convert an uncontrolled dwell risk into a managed, priced standby phase.

5.5 Procuring and Governing Preservation Services

Preservation is usually bought, not built, which makes it a procurement problem with its own literature. Process automation frameworks for procurement efficiency and transparency (Akinleye and Adeyoyin, 2021) and integrated digital platforms for procurement transparency (Okoruwa *et al*., 2024) describe the systems through which preservation scopes, service records, and payments can be made visible to all parties rather than buried in a storage contractor's internal files. Supplier relationship management frameworks aimed at strategic objectives (Akinleye and Adeyoyin, 2022b) and cross-border relationship management across construction and regulated sectors (Akin-Oluyomi *et al*., 2024) address the multi-year, multi-jurisdiction character of a standby relationship, while negotiation optimization models for cost reduction (Akinleye and Adeyoyin, 2022a) apply to the commercial structuring of long storage terms where the buyer's leverage declines as hardware sits in a supplier's yard.

Supplier risk itself needs assessment. Regulatory compliance and supplier risk assessment frameworks developed for tightly regulated procurement (Akin-Oluyomi *et al*., 2023c) and data-driven procurement risk management models for multinational enterprises (Bello *et al*., 2023) provide the screening logic for selecting a storage or preservation provider whose failure would be difficult to remedy once hardware is committed. Big data and business intelligence applications in procurement (Akinleye *et al*., 2023) and predictive demand forecasting for procurement systems (Akin-Oluyomi *et al*., 2023d) sharpen the consumables and spares planning that a long preservation program depends on. Sustainable and lean framing completes the picture: Sustainable procurement frameworks for manufacturing enterprises (Efobi *et al*., 2022a), data-driven lean supply chain optimization (Efobi *et al*., 2022b), lean supply chain practice for waste reduction and operational efficiency (Ike *et al*., 2022), and supply chain resilience indices developed after pandemic disruption (Efobi *et al*., 2023) each contribute criteria by which a preservation scope can be judged efficient rather than merely thorough.

Finally, the operational discipline literature for smaller service organizations is unexpectedly apt, because preservation work is often executed by modest local contractors rather than major EPC firms. Standard operating procedures treated as strategic assets (Eyetsemitan *et al*., 2022), Lean Six Sigma adaptation frameworks for resource-constrained organizations (Ambali *et al*., 2021), and process redesign methods for cycle time reduction (Oyeleye *et al*., 2022) describe how such organizations achieve repeatable quality, which is precisely what a multi-year preservation schedule requires of them.

5.6 An Illustrative Cost Comparison

A stylized comparison makes the asymmetry concrete. Consider a floating wind mooring package for a modest array, with hardware value in the tens of millions of dollars and a planned standby of eighteen months that project risk analysis says could stretch to thirty. A full preservation program, baseline recording, classified covered storage for connectors and ropes, open serviced storage for chain and anchors, clamp anode protection and two survey campaigns for pre-laid ground legs, scheduled tasks, audits, and dossier administration, prices at roughly one to two percent of hardware value per year. Against this, a single failed mobilization scenario is easily an order of magnitude larger: Replacement of a batch of storage-corroded connectors at expedited pricing, a rope order whose witness samples failed break tests, ten days of anchor handling vessel standby at day rates in the low hundreds of thousands, and, if the recovery slips past the weather window, a season's deferral of first power with its financing consequences. The comparison is deliberately coarse, and Section 12 calls for formal probabilistic treatment, but its structure explains observed behavior: Experienced floating asset operators preserve as a matter of routine, while first-time developers, seeing only the visible spend, are the population from which mobilization failure stories are drawn. Preservation budgets survive value engineering best when they are presented in this insurance form, with the priced counterfactual attached, rather than as a line item of yard services. The financial analytics literature offers the modeling vocabulary for making that case rigorously: Capital allocation decision models built on financial analytics (Lawal and Oduleye, 2021a), predictive cost optimization models applied to business transformation (Tonoyan *et al*., 2022c), algorithmic process optimization with financial impact assessment (Tonoyan *et al*., 2022b), integrated predictive analytics for strategic financial forecasting (Medon and Oduleye, 2024), and cash flow and working capital optimization models (Oduleye and Medon, 2023a) collectively supply the apparatus for expressing preservation as an investment with a modeled return, rather than as an operating cost to be minimized.

6. A Risk-Based Framework for Standby Integrity Management

The preservation specification of Section 3.7 tells a project what to do; a risk framework tells it how much is enough and where to concentrate effort. This section outlines a five-step framework that adapts established asset risk practice to the standby phase.

Step 1: Hazard identification by storage mode: For each component class in each storage regime, the credible degradation and damage hazards are enumerated: the corrosion, ingress, creep, fouling, handling, and certification decay mechanisms cataloged in Section 2, plus site-specific hazards such as fishing interaction over wet stored lines, flood exposure of laydown areas, or theft and vandalism. Digital safety data streams and hazard observation programs (Arumosoye and Obriki, 2019; Obriki and Arumosoye, 2023) feed this register with actual yard experience rather than generic lists.

Step 2: Likelihood and consequence assessment: Likelihood reflects the storage environment classification and the preservation level applied; consequence reflects the component's criticality, replacement lead time, and requalification burden. A corroded shackle with a two-week replacement lead time is a nuisance; a compromised 150 mm chain segment with an eighteen-month lead time is a project event. Consequence scoring must therefore include schedule exposure, not only replacement cost, which is the insight the economic analysis of Section 5 contributes.

Step 3: Barrier definition and verification: Each significant hazard is assigned preventive barriers (preservation measures, environmental controls, handling procedures) and detective barriers (scheduled inspections, CP surveys, function tests, monitoring sensors). The monitoring architecture of Section 4.2 is then understood not as data collection for its own sake but as barrier verification: each survey or sensor exists to confirm a named barrier is intact. Continuous hazard monitoring concepts (Obriki *et al*., 2023a) and interpretable anomaly detection (Komi and Adamolekun, 2021) make the detective layer proportionate to a dormant asset's low activity.

Step 4: Residual risk and requalification scoping: The residual risk after barriers determines the requalification scope at mobilization. Components whose barriers held throughout storage, with records to prove it, requalify by documentation review and sample verification. Components with barrier failures, environmental excursions, or record gaps carry escalating scopes up to retrieval and destructive testing. This is where the reliability updating machinery of Section 4.1 (Rezende *et al*., 2024; Li *et al*., 2024) attaches: verified preservation narrows the prior damage distribution, which quantitatively reduces the inspection burden required to achieve the target reliability.

Step 5: Review and learning: The register is a living document reviewed on a fixed cadence and after every incident, near miss, or failed acceptance test, with incident investigation and prevention-oriented learning practices (Obriki and Arumosoye, 2024b) closing the loop into revised barriers and revised specifications. Organizational learning is what converts one project's mobilization surprises into the next project's preservation matrix entries.

Two supporting disciplines make the framework operable. The first is quantification: risk-based auditing models for strategic financial management (Akomolafe *et al*., 2023a), technology-enabled internal audit quality frameworks (Akomolafe and Agu, 2018), and cyber risk quantification models for prioritizing investment (Dosunmu and Ogundele, 2024b) all demonstrate how qualitative registers are converted into ranked, resourced action, which is what distinguishes a risk framework from a hazard list. The second is performance measurement: performance intelligence models for large service programs (Adelanwa *et al*., 2024) and data-driven digital transformation models for lifecycle performance management in infrastructure delivery (Adelanwa *et al*., 2023a) provide the indicator structures by which a standby program's health is judged before mobilization exposes it.

The framework's practical output is differentiation: most of the package receives standard care, a small critical subset receives intensive care, and the evidence trail for both is proportionate to what requalification will later demand.

7. Case Perspectives

Three documented settings illustrate the review's themes in practice.

7.1 FPSO Mooring Life Extension as the Requalification Template

The published life extension assessment of an FPSO mooring system in the South China Sea (Wang *et al*., 2019), in which chain segments were retrieved after two decades of service for inspection, finite element analysis, and residual breaking strength tests feeding a system reliability evaluation and code compliance check, remains the clearest template for evidence-based requalification of steel mooring components. Every element of that workflow, retrieval sampling, condition quantification, strength verification, reliability recalculation, and code check, transfers to the post-storage question with the timescale compressed from twenty years to twenty months. The case also demonstrates the cost asymmetry that motivates preservation: the assessment program was expensive precisely because the historical condition record was thin, forcing physical verification to substitute for documentation. A wet storage campaign that begins with a baseline record and maintains CP verification surveys can expect to requalify largely on paper, which is the economic point of Sections 3.7 and 6.

7.2 Multi-Campaign Pre-Lay for a Floating Wind Farm

The published installation logistics study for a 47 platform floating wind farm off Lannion (Rivera Arreba *et al*., 2022), with 141 mooring lines pre-laid across seven campaigns using paired large anchor handling vessels, quantifies the standby phase that this review addresses. With line installation running at roughly a day per line per vessel and tensioning operations sequenced behind, the first lines of a campaign season inevitably wait months for their floaters, and weather limits on towing and hook-up stretch the tail. The study's weather window analysis makes standby duration a planned statistical quantity, which is exactly the input the risk framework of Section 6 requires: expected and upper-percentile storage durations per line, from which preservation provisions and survey intervals can be sized line by line rather than uniformly. Renewable forecasting advances (Komi, 2021) tighten those duration distributions further.

7.3 Inshore Wet Storage of Substructures and Their Temporary Moorings

The inshore mooring practice documented by major mooring contractors for floating wind hull wet storage (Acteon, 2024), in which temporary spreads are designed, procured, pre-laid, and later recovered as a rental service, illustrates the integrated contracting model of Section 5.3 operating today. The port requirements literature adds the spatial dimension (Crowle and Thies, 2022; GHD, 2024): wet storage areas of ten to twelve hectares with temporary moorings, dedicated mooring and anchor laydown, and drum storage for synthetic rope are now explicit port planning line items. The instructive detail is that the temporary moorings securing wet stored hulls are themselves mooring packages in standby-like service, inspected and maintained on in-service intervals even though the assets they hold are idle. The sector has, in effect, already conceded the central argument of this review for its temporary equipment; extending the same discipline to the permanent packages awaiting deployment is the remaining step.

Across the three settings, the common lesson is that evidence is the currency of standby: where condition records and protection verification exist, requalification is administrative; where they do not, it is physical, slow, and expensive.

8. Standards, Joint Industry Programs, and Regulatory Context

Several coordinated efforts frame the 2024 landscape:

- **Floating Wind JIP work on wet storage and quick connectors** (Carbon Trust, 2024) examined the risks and enabling role of wet storage for mooring and connection assemblies, including corrosion and marine growth of submerged connectors, cable integrity after seabed storage, and the liability and interface complexity arising when no single supplier owns the whole connection assembly.
- **ISO 25249 (proposal accepted 2024, in committee review)** (PPG, 2024) promises a comprehensive corrosion protection framework for offshore wind covering coatings, cathodic protection, environmental assessment, and maintenance strategy across total service life.
- **Mooring integrity management guidance for floating wind** (World Forum Offshore Wind, 2023), issued through industry white papers, established MIM as a life cycle process spanning design, manufacturing, installation, and operation, providing the natural home for standby preservation requirements.
- **Classification society and code check practice** for life extension, demonstrated in published FPSO case studies involving retrieval, inspection, FEA, and break testing of chain after two decades of service (Wang *et al*., 2019), continues to supply the verification vocabulary being adapted for post-standby requalification.
- **Port and marshalling infrastructure planning** for floating wind (Crowle and Thies, 2022; GHD, 2024) now formally recognizes mooring and anchor storage needs, wet storage areas of 10 to 12 hectares for substructures with associated temporary moorings, and drum storage of synthetic rope, embedding preservation-aware logistics into port development criteria (Crowle and Thies, 2022; GHD, 2024).

Remaining standardization gaps include: maximum recommended wet storage durations by component class and environment; harmonized requalification test matrices after storage; preservation record requirements for certification currency; and synthetic rope condition assessment after long storage. Closing these gaps will require governance instruments as much as technical criteria. Conceptual frameworks for digital supply chain governance in the energy and infrastructure sectors (Okonkwo *et al*., 2024a) and conceptual environmental safety compliance frameworks for construction and infrastructure projects (Obogo *et al*., 2024b) offer templates for embedding preservation duties, verification rights, and record obligations into the contractual chain that surrounds a stored mooring package. Because standby records and monitoring feeds increasingly live in connected digital systems, security architecture models for IT and OT convergence in regulated energy networks (Adegbite *et al*., 2022) are relevant to protecting the integrity of the MIM record itself, while blockchain-driven ESG compliance reporting for energy projects (Abioye *et al*., 2023) and AI-assisted ESG auditing of infrastructure (Okojie *et al*., 2023a) suggest mechanisms for making preservation and environmental performance during storage externally verifiable.

8.1 Classification and Verification Practice

Classification societies occupy the pivotal verification role for stored mooring equipment because component certificates, proof load records, and NDE documentation are issued under their schemes and lapse under their rules. Practice through 2024 shows movement on three fronts. First, surveyors increasingly accept preservation records and CP verification surveys as partial substitutes for physical re-examination when scoping post-storage surveys, provided the records regime was agreed before storage began, which rewards projects that engage class at the specification stage rather than at mobilization. Second, the life extension assessment vocabulary, condition quantification feeding reliability evaluation feeding code check, is being reused verbatim for storage requalification, giving Pathways B through D of Section 4.4 a recognized verification grammar. Third, class involvement is extending upstream into storage itself, with periodic survey attendance at long-duration laydown and wet storage sites emerging as a service line, mirroring the in-service survey cycle. The open question is uniformity: scoping decisions remain surveyor-discretionary, and until class guidance codifies storage duration thresholds and record standards, requalification scopes will continue to vary between projects with similar facts.

8.2 Jurisdictional and Environmental Permitting Considerations

Standby also has a regulatory geography. Wet storage of mooring lines and anchors occupies seabed, and most shelf jurisdictions treat pre-laid equipment as a licensable activity with conditions on duration, marking, fishing industry notification, and eventual recovery, so that wet storage permits can themselves become the binding constraint on standby duration. Onshore, long-held project cargo interacts with customs regimes, free zone rules, and environmental controls on washdown water, blasting residues, and inhibitor handling in marshalling yards; environmental safety compliance frameworks for construction and infrastructure projects (Obogo *et al*., 2024b) and sustainable environmental practice reviews within safety management systems (Obogo *et al*., 2024a) map the compliance surface that a preservation yard must manage. Cross-border movements of packages between manufacture, storage, and installation jurisdictions multiply these interfaces, which is where regulatory compliant procurement frameworks for high-risk energy environments (Okonkwo *et al*., 2021b) earn their place in the mooring context. The practical recommendation is early jurisdictional mapping: a standby plan that identifies every permit, notification, and environmental condition attached to each storage location, with expiry dates entered into the same dossier that tracks component certificates, so that administrative validity and physical condition are managed as the single readiness question they jointly constitute.

8.3 Lessons from Adjacent Regulated Sectors

Three regulated sectors have already built the oversight machinery that mooring standby now needs, and their models are instructive.

Civil aviation offers the closest analogue for periodic certification of assets whose condition must be demonstrated rather than assumed. Adaptive safety management system implementation models for aerodromes (Adeyelu, 2019), comparative benchmarking models for certification compliance across regulators (Adeyelu and Dagodzo, 2022), maturity models for predicting safety audit outcomes in resource-constrained regulatory environments (Adeyelu and Dagodzo, 2024), and predictive compliance monitoring frameworks that mine routine reporting for systemic risk signals (Adeyelu, 2018) together describe an oversight regime built on maturity assessment, benchmarking, and leading indicators rather than episodic inspection. That is the direction class oversight of stored mooring equipment appears to be heading, and the aviation experience suggests both its benefits and its variability problem.

Pharmaceutical supply chain regulation offers the closest analogue for custody of certified goods across jurisdictions and time. Regulatory readiness maturity models for market entry (Eze *et al*., 2022b), supply chain governance frameworks linking environmental risk management to sustained product access (Eze *et al*., 2023), early warning models for supply disruption (Eze *et al*., 2022a), and cross-border regulatory harmonization models (Eze *et al*., 2024a) address exactly the problem of goods whose fitness depends jointly on documented storage conditions and unexpired approvals, which is the mooring standby problem in a different material.

Critical infrastructure cybersecurity offers the analogue for protecting the digital records on which documentary requalification depends. Systematic reviews of operational technology network security and compliance in electric utilities (Adegbite *et al*., 2020), ICS and SCADA threat detection architectures (Adegbite *et al*., 2023), vulnerability governance architectures spanning exposure mapping to remediation verification (Adegbite *et al*., 2024a), zero trust architectures for operational technology (Ahmed *et al*., 2021), machine learning approaches to ICS anomaly detection (Adebayo *et al*., 2023), enterprise security audit and risk assessment frameworks (Dosunmu and Ogundele, 2019), and data privacy governance models for cross-border digital platforms (Annan, 2022) collectively define the assurance regime appropriate to a dossier that will be relied upon, years later, as evidence of fitness for service.

9. Human and Organizational Factors

Standby preservation fails organizationally before it fails technically. Four human factors deserve explicit treatment.

Attention decay over long dormancy: A yard crew's vigilance, like a monitoring program's budget, erodes over a standby period measured in years, and the low event rate of a well-preserved stockpile paradoxically starves the safety and integrity system of the feedback that sustains attention. Structured near-miss and hazard observation programs (Arumosoye and Obriki, 2019) counter this by manufacturing feedback: every scheduled task becomes an observation opportunity, and observation rates themselves become a leading indicator of program health. Continuous hazard monitoring approaches (Obriki *et al*., 2023a) automate part of the vigilance so that human attention is spent where judgment is needed.

Multi-party interfaces and diffuse accountability: A mooring package can pass through a manufacturer's yard, a freight forwarder, a marshalling port authority, a storage contractor, a survey house, and an installation contractor before it ever carries load. Each handover is an opportunity for preservation duties, records, and liabilities to fall between parties. Governance models for contractor safety performance in multi-contract projects (Arumosoye and Obriki, 2020) generalize directly: named accountable parties per phase, interface registers, and handover acceptance criteria that include preservation state, not only quantity and identity. The integrated contracting model discussed in Section 5.3 is, at root, an organizational simplification that removes interfaces.

Competence and procedural discipline: Preservation tasks look mundane, and mundane tasks drift. Torque checks get pencil-whipped, desiccant changes slip, washdowns skip the hard-to-reach stacks. Incident prevention models for maintenance environments (Obogo *et al*., 2021b) and data-driven safety risk control frameworks for large energy infrastructure (Obriki and Arumosoye, 2018) both locate the countermeasure in the same place: task-level procedures with verification steps, sampled independent checks, and consequence management that treats record falsification as the serious integrity breach it is. Emergency response readiness (Arumosoye and Obriki, 2023) belongs in the same competence envelope, because storage sites hold heavy suspended loads, pressurized systems, and, at wet storage sites, marine operations exposure. Training effectiveness research from an adjacent domain, on how awareness programs shift risk-relevant behavior in organizations (Onche *et al*., 2024), reinforces a point the safety literature makes repeatedly: awareness interventions change behavior durably only when they are recurrent, role-specific, and reinforced by supervision, which is a demanding standard to sustain across a multi-year dormancy.

Knowledge continuity across the standby valley: The people who put a package into storage are rarely the people who take it out. The mobilization team inherits whatever the records convey and nothing else. This is the human argument for the digital dossier of Section 4.3: the record is not bureaucracy, it is the mechanism by which the storage organization's knowledge survives into the installation organization. Projects that staff a continuous package custodian role, even part time, across the whole standby period report markedly smoother mobilizations, because the custodian carries the tacit knowledge that records inevitably miss.

10. Discussion

Five themes emerge from the 2024 body of work and the adjacent literatures synthesized above.

First, standby is becoming a designed condition: Pre-lay and wet storage are no longer schedule accidents but deliberate installation strategies, planned in multi-campaign programs with defined vessel spreads and weather limits. It follows that the standby environment, duration distribution, and preservation measures should be specified in the mooring design basis, with corrosion allowances, coating systems, and anode provisions sized for storage plus service. Retrofit clamp anode technology and TSA coatings give designers practical tools to do this without redesigning the chain itself.

Second, preservation and integrity management are converging: The historical division between "preservation" (a warehousing activity) and "integrity management" (an operations activity) is dissolving. Reliability-based inspection frameworks that admit a prior damage state, monitoring of dormant lines, and MIM dossiers initiated at manufacture together allow the standby phase to be managed with the same rigor, and the same digital records, as the operating phase. This convergence is commercially reinforced by integrated contractor models that bundle wet storage mooring design, equipment rental, preservation, and hook-up. It is further supported by procurement research: models for predictive procurement planning to sustain operational uptime (Okonkwo *et al*., 2024b) argue for anticipating readiness requirements rather than reacting to shortfalls, and models for demurrage elimination and port logistics efficiency in emerging economies (Okonkwo *et al*., 2020) speak directly to the marshalling port congestion and dwell-time costs that lengthen mooring package standby in the first place. Predictive models for vendor risk assessment and procurement cost optimization (Tonoyan *et al*., 2024a) and predictive analytics for supply chain demand forecasting and inventory efficiency (Aifuwa *et al*., 2020) round out the toolset, allowing operators to anticipate which stored components, spares, and consumables will actually be needed at hook-up and to hold suppliers of preservation services to measurable performance standards. Vendor-facing tools complete the picture: data driven vendor evaluation and bid selection using geospatial intelligence (Ahiaeke Patrick *et al*., 2021), supplier relationship management strategies that foster resilience across global supply chains (Ike *et al*., 2021), supplier sustainability metrics embedded in data-driven procurement frameworks (Akin-Oluyomi *et al*., 2023b), regulatory compliant procurement frameworks for high-risk energy environments (Okonkwo *et al*., 2021b), and secure, scalable supply chain systems supporting national energy reliability (Okonkwo *et al*., 2024c), together with reviews of procurement strategy, ERP adoption, and logistics performance (Okonkwo *et al*., 2024d) and digital supply chain models for cost control and operational continuity (Okonkwo *et al*., 2024e), collectively describe the procurement governance within which preservation service providers should be selected, contracted, and managed. Resilient logistics frameworks integrating predictive analytics and IoT (Anene and Clement, 2022) and programmatic strategies drawn from large-scale renewable energy deployments (Yeboah and Ike, 2020) add planning patterns for the mobilization surge that ends a standby period.

Fourth, the economics reward early commitment: The cost analysis of Section 5 and the case evidence of Section 7 point the same way: preservation expenditure is small, steady, and controllable, while the alternative exposure is large, episodic, and schedule-coupled. Because the decisive costs are avoided rather than incurred, preservation competes poorly for budget in organizations that account only for visible spend, and the discipline therefore needs to be locked in contractually and in the design basis before standby begins, when the counterfactual is still vivid. Projects that defer the preservation decision until hardware is already sitting in a yard have usually already lost the baseline condition record on which cheap requalification depends.

Fifth, the standby problem is a systems integration problem: No single discipline owns it. Corrosion science supplies the mechanisms, procurement supplies the contracts, safety management supplies the yard discipline, sensing and analytics supply the evidence stream, class supplies the verification grammar, and regulators supply the permitting envelope. The projects that manage standby well are not those with the best technology in any one lane but those that integrate the lanes: a single specification, a single risk register, a single dossier, and a single accountable custodian. That integrative character is why this review has drawn so widely on adjacent literatures, and it is also why the standardization agenda of Section 12 matters: shared frameworks are what allow the integration to be reproduced across projects rather than reinvented within them.

Third, connectors and synthetic elements are the soft spots: Chain preservation is comparatively well understood and now actively protectable. The larger residual uncertainties sit with machined connector interfaces, quick connectors intended for subsea dormancy, dynamic cable connection assemblies, and fiber ropes after long storage. These are precisely the components on which floating wind serialization depends, and they are the focus of current JIP attention. Until standardized requalification protocols exist, project-specific preservation specifications with conservative inspection scopes remain necessary.

11. Limitations of This Review

Four limitations qualify the conclusions that follow. First, this is a narrative synthesis, not a systematic review: source selection followed relevance judgment rather than a registered protocol, and no formal quality scoring or effect pooling was performed, so the weight given to individual sources reflects editorial assessment. Second, the evidence base is heterogeneous, mixing peer reviewed studies, joint industry programme outputs, standards drafts, and vendor literature; the latter two categories serve the review's currency but carry obvious interest and maturity caveats. Third, many of the governance, safety, and analytics frameworks imported from adjacent sectors are conceptual models whose transfer to mooring standby is argued by analogy rather than demonstrated by field trial; the direction of transfer is plausible, but quantitative performance in the mooring context remains to be established. Fourth, the review's 2024 cutoff means that in-progress activities, including the ISO 25249 committee process and ongoing JIP phases, are captured at a point in time and their eventual outputs may differ from the trajectories described here. None of these limitations, in the authors' judgment, threatens the review's central claims, which rest on convergent evidence across independent streams, but each argues for the primary research agenda of Section 12.

12. Future Research Directions

Seven research needs emerge from the gaps identified across this review.

Degradation rate data for dormant conditions: The single largest quantitative gap is measured corrosion and MIC rate data for chain and connectors in genuine wet storage conditions: on and in sediment, unprotected and protected, across sediment types and temperatures. A coordinated coupon and retrieved-sample program across active pre-lay projects would replace the current practice of borrowing in-service touchdown zone rates that were never derived for stagnant burial.

Wet storage duration limits by component class: Standards bodies need defensible maximum storage durations, with and without active protection, per component class and environment. This requires combining the degradation data above with the reliability updating methods already in hand (Rezende *et al*., 2024; Li *et al*., 2024) to define duration thresholds at stated reliability targets, giving the industry the tables it currently improvises project by project.

Non-destructive requalification of synthetic ropes: Fiber rope condition after multi-year storage is presently inferred from jacket inspection and witness break tests. Research into embedded fiber optic sensing, stiffness signature testing, and acoustic methods that can grade a stored rope without destroying sample lengths would remove one of the most expensive and least satisfactory steps in current requalification practice.

Long-endurance dormant asset sensing: The energy autonomous sensing trajectory (Asiedu and Quainoo, 2023a; Asiedu and Quainoo, 2023b; Asiedu and Quainoo, 2024) needs marinized field trials: batteryless or energy harvesting nodes on buoyed off line ends and stored equipment, surviving realistic biofouling and sea states across a full standby period, with interpretable anomaly detection (Komi and Adamolekun, 2021) sized to their duty cycles.

Digital thread standardization: Component-level traceability from manufacture through storage into the operational MIM dossier currently relies on project-specific implementations. A standardized data model for mooring component identity, condition, preservation history, and certification state, building on asset lifecycle visibility concepts (Okonkwo *et al*., 2023; Nnabueze *et al*., 2021) and secured to critical infrastructure expectations (Adegbite *et al*., 2022), would let records survive contractor changes and software generations.

Economic models of preservation value: The insurance framing of Section 5 deserves formal treatment: probabilistic schedule risk models that price preservation options against mobilization delay distributions, giving developers a defensible basis for preservation budgets and giving insurers a basis for recognizing preservation quality in coverage terms.

Organizational performance evidence: Finally, the human factors claims of Section 9, on custodianship, interface management, and attention decay, rest largely on transferred models. Longitudinal studies of actual standby programs, correlating organizational arrangements with mobilization first-pass acceptance rates, would convert reasonable practice into evidenced practice.

Two adjacent trajectories are worth tracking because they will shape the operating context of future standby programs. The first is the evolution of grid-side and distributed energy infrastructure, where reviews of smart grid architecture for high renewable penetration (Adenuga, 2022), control architectures for distributed energy resources (Komi and Adamolekun, 2022), and edge intelligence for resilient microgrid control (Komi and Ganiu, 2023) describe the systems into which floating wind arrays must eventually deliver, and whose commissioning schedules set the deadlines that make mooring standby duration consequential. The second is the growing use of data-driven decision systems across infrastructure delivery, where predictive analytics applied to logistics and localized supply networks (Anene and Clement, 2024) and real-time performance monitoring architectures (Tonoyan *et al*., 2024b) point toward standby programs whose readiness state is continuously visible to project controls rather than discovered at mobilization.

13. Conclusions and Recommendations

1. Extended standby of offshore mooring packages, onshore and subsea, is now a structural feature of floating offshore projects, driven especially by floating wind pre-lay logistics and supply chain lead times, and it introduces degradation mechanisms and certification risks distinct from the in-service phase.
2. 2024 saw material advances in standby preservation capability, including commercially available retrofit clamp-mounted sacrificial anode systems for chain with supporting protection modeling and verification, matured TSA and coating practice for connectors and tensioned elements, and systematic VCI and controlled-environment preservation of connectors, ropes, and mechanical equipment.
3. Reliability-based inspection planning and fatigue reliability methods published in 2024 provide the analytical machinery to carry storage-phase degradation into in-service integrity management as a quantified prior damage state.
4. Industry programs on wet storage and quick connectors, the acceptance of the ISO 25249 proposal for comprehensive offshore wind corrosion protection, and floating wind MIM frameworks collectively signal that standards are catching up with practice, but harmonized wet storage duration limits and post-storage requalification protocols, particularly for synthetic ropes and quick connectors, remain open needs.
5. It is recommended that operators and developers: (a) include standby duration and environment in the mooring design basis; (b) specify active corrosion protection for wet stored chain from pre-lay; (c) initiate the MIM digital record at manufacture and log all preservation and monitoring actions through standby; (d) assign single-party contractual responsibility for

preservation across storage and hook-up; and (e) support JIP and standards work toward standardized post-storage requalification; (f) adopt the tiered requalification pathways of Section 4.4 and pre-agree them with class and installation contractors so acceptance scopes are determined by records and risk rather than negotiated at mobilization; (g) apply the risk-based differentiation of Section 6 so that preservation intensity, monitoring, and requalification burden concentrate on components whose criticality and lead time actually warrant them; and (h) resource the human side deliberately, with a named package custodian across the standby period, interface handover criteria that include preservation state, and audit regimes that keep task discipline honest over years of low-event dormancy.

Treating standby as a managed life cycle phase, with preservation engineered rather than improvised, protects not only the mooring hardware but the schedule and economics of the floating offshore projects that depend on it.

14. References

1. Abioye RF, Okojie JS, Filani OM, Ike PN, Idu JOO, Nnabueze SB, *et al*. Automated ESG reporting in energy projects using blockchain-driven smart compliance management systems. International Journal of Multidisciplinary Evolutionary Research. 2023; 4(2):120-129. Doi: https://doi.org/10.54660/IJMER.2023.4.2.120-129
2. Acteon. Inshore mooring solutions for floating wind, 2024. https://acteon.com/insights/blogs/inshore-mooring-solutions-floating-wind
3. Adebayo A, Adegbite MP, Ahmed MO. AI augmented threat detection in industrial control systems: A systematic review of machine learning approaches for ICS anomaly detection. International Journal of Engineering and Modern Technology. 2023; 9(2):61-96.
4. Adegbite MP, Adebayo A, Ahmed MO. Securing operational technology networks in electric utilities: A systematic review of NERC CIP compliance and architectural threat mitigation. International Journal of Engineering and Modern Technology. 2020; 6(3):74-110.
5. Adegbite MP, Adebayo A, Ahmed MO. A security architecture model for IT and OT convergence in regulated energy networks: Design principles and governance alignment. International Journal of Computer Science and Mathematical Theory. 2022; 8(2):81-132. Doi: https://doi.org/10.56201/ijcsmt.v8.no2.2022.pg81.132
6. Adegbite MP, Adebayo A, Ahmed MO. ICS and SCADA threat detection architectures in energy sector networks: A systematic review of SIEM, NDR, and anomaly detection approaches. World Journal of Innovation and Modern Technology. 2023; 7(3):55-92.
7. Adegbite MP, Adebayo A, Ahmed MO. A vulnerability governance architecture for power and utilities corporations: From exposure mapping to remediation verification. World Journal of Innovation and Modern Technology. 2024a; 8(4):88-124.
8. Adelanwa A, Basnet A, Anene UN. Data driven digital transformation models for lifecycle performance management in infrastructure delivery. International Journal of Advanced Multidisciplinary Research and Studies. 2023a; 3(6):2405-2419.
9. Adelanwa A, Basnet A, Anene UN. Performance intelligence models for optimization and outcome measurement in large scale public services. Shodhshauryam, International Scientific Refereed Research Journal. 2024; 6(1):512-533.
10. Adenuga OM. Smart grid architectures and energy distribution for high renewable penetration: A comprehensive review of technologies, operations, and deployment pathways. International Journal of Engineering and Modern Technology. 2022; 8(3):55-98.
11. Adeyelu OO. A predictive compliance monitoring framework for detecting systemic safety risks through aviation consumer complaint data. Iconic Research and Engineering Journals. 2018; 1(8):250-276. Doi: https://doi.org/10.64388/IREV1I8-1718476
12. Adeyelu OO. An adaptive safety management system implementation model for aerodromes in developing economy contexts. Iconic Research and Engineering Journals. 2019; 3(4):628-654. Doi: https://doi.org/10.64388/IREV3I4-1718479
13. Adeyelu OO, Dagodzo D. A comparative benchmarking model for aerodrome certification compliance across developing economy civil aviation authorities. International Journal of Multidisciplinary Research and Growth Evaluation. 2022; 3(6):900-928.
14. Adeyelu OO, Dagodzo D. A maturity model for predicting airport safety audit outcomes in resource-constrained regulatory environments. International Journal of Scientific Research in Civil Engineering. 2024; 8(4):132-171.
15. Agbabiaka J, Okonkwo CS, Ogunwole O, Mayo W, Okeke OT. Supply chain risk management model for EPC and gas processing projects. Iconic Research and Engineering Journals. 2019; 3(2):968-980. Doi: https://doi.org/10.64388/IREV3I2-1713124
16. Ahiaeke Patrick MC, Okonkwo CS, Mayo W, Okeke OT. A GIS enabled framework for modern ERP procurement processes. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):499-508. Doi: https://doi.org/10.54660/IJMRGE.2020.1.5.499-508
17. Ahiaeke Patrick MC, Okonkwo CS, Mayo W, Okeke OT. Model for data driven vendor evaluation and bid selection using geospatial intelligence. Shodhshauryam, International Scientific Refereed Research Journal. 2021; 4(4):426-443. Doi: https://doi.org/10.32628/SHISRRJ214461
18. Ahmed MO, Adegbite MP, Adebayo A. Zero trust architecture for operational technology in North American critical infrastructure: A framework for implementation and resilience optimization. International Journal of Engineering and Modern Technology. 2021; 7(2):44-83.
19. Aifuwa SE, Oshoba TO, Ogbuefi E, Ike PN, Nnabueze SB, Olatunde-Thorpe J. Predictive analytics models enhancing supply chain demand forecasting accuracy and reducing inventory management inefficiencies. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(3):171-181. Doi: https://doi.org/10.54660/.IJMRGE.2020.1.3.171-181
20. Akanbi O, Sunday EA. An integrated path-planning and

slotting optimization model for AMR-enabled high-density warehousing. International Journal of Advanced Multidisciplinary Research and Studies. 2024; 4(6):3226-3243.
21. Akin-Oluyomi OT, Atima ME, Akinleye OK, Okoruwa PO. Predictive analytics approaches for improving demand forecasting accuracy in e-commerce procurement systems. International Journal of Advanced Multidisciplinary Research and Studies. 2023d; 3(6):2204-2212.
22. Akin-Oluyomi OT, Atima ME, Akinleye OK. Green procurement strategies for balancing cost efficiency with long-term environmental responsibility. International Journal of Advanced Multidisciplinary Research and Studies. 2023a; 3(6):2183-2193.
23. Akin-Oluyomi OT, Atima ME, Akinleye OK. Regulatory compliance and supplier risk assessment frameworks in international pharmaceutical procurement. International Journal of Advanced Multidisciplinary Research and Studies. 2023c; 3(6):2194-2203.
24. Akin-Oluyomi OT, Atima ME, Akinleye OK. Cross-border supplier relationship management frameworks for pharmaceutical and global construction sectors. International Journal of Multidisciplinary Research and Growth Evaluation. 2024; 5(6):1621-1633.
25. Akin-Oluyomi OT, Okoruwa PO, Babatope OM, Akokodaripon DA. Evaluating supplier sustainability metrics through data-driven procurement and supply chain frameworks. International Journal of Advanced Multidisciplinary Research and Studies. 2023b; 3(6):2213-2223.
26. Akinleye OK, Adeyoyin O. Process automation framework for enhancing procurement efficiency and transparency. Shodhshauryam, International Scientific Refereed Research Journal. 2021; 4(4):356-387.
27. Akinleye OK, Adeyoyin O. A negotiation optimization model for reducing procurement costs in manufacturing firms. Shodhshauryam, International Scientific Refereed Research Journal. 2022a; 5(5):398-435.
28. Akinleye OK, Adeyoyin O. Supplier relationship management framework for achieving strategic procurement objectives. Gyanshauryam, International Scientific Refereed Research Journal. 2022b; 5(4):565-598.
29. Akinleye OK, Okoruwa PO, Babatope OM, Akokodaripon DA. Leveraging big data and business intelligence for optimization of manufacturing sector procurement. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2224-2234.
30. Akomolafe O, Agu MU, Bello A. A conceptual model for implementing risk-based auditing in strategic financial management. International Journal of Advanced Multidisciplinary Research and Studies. 2023a; 3(6):2274-2286.
31. Akomolafe O, Agu MU. A conceptual model for enhancing internal audit quality through technology-enabled risk assessment frameworks. Iconic Research and Engineering Journals. 2018; 1(9):458-475.
32. Aliliele C, Mbonu IS, Iwuanyanwu U. A conceptual framework for enterprise data sensitivity classification and regulatory traceability mechanisms. International Journal of Advanced Multidisciplinary Research and Studies. 2024a; 4(6):2966-2985.
33. Amayo EB, Owulade OA, Isi LR. Optimizing project governance in multinational infrastructure projects: Insights from global operations. International Journal of Multidisciplinary Research and Growth Evaluation. 2023a; 4(1):761-770.
34. Amayo EB, Owulade OA, Isi LR. Best practices for managing data center lifecycle projects: Ensuring security, efficiency, and compliance. Iconic Research and Engineering Journals. 2024a; 7(7):512-531.
35. Amayo EB, Owulade OA, Isi LR. Effective project governance in multinational infrastructure projects: A case study. Iconic Research and Engineering Journals. 2024b; 8(5):1305-1324.
36. Amayo EB, Owulade OA, Isi LR. Strategic project management approaches for successful solar energy deployments in emerging markets. Iconic Research and Engineering Journals. 2024c; 7(11):448-467.
37. Ambali KB, Eyetsemitan RA, Oyeleye AO, Fadayomi O. Lean Six Sigma for small enterprises: A systematic review and Lite-DMAIC adaptation framework for resource-constrained organizations. Iconic Research and Engineering Journals. 2021; 5(2):341-362.
38. Anene UN, Clement T. A resilient logistics framework for humanitarian supply chains: Integrating predictive analytics, IoT, and localized distribution to strengthen emergency response systems. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2022; 8(5):398-424.
39. Anene UN, Clement T. Localized supply chain solutions for sustainable community development: A strategic model for economic revitalization and regional resilience. International Journal of Scientific Research in Science and Technology. 2024; 11(6):622-645.
40. Annan AO. Data privacy governance models for cross-border digital platforms. International Journal of Multidisciplinary Research and Growth Evaluation. 2022; 3(6):949-964.
41. Arumosoye OM, Obriki OD. Development of an integrated heat stress risk conceptual model for industrial operations in extreme environments. Iconic Research and Engineering Journals. 2018; 1(12):141-160. Doi: https://doi.org/10.64388/IREV1I12-1714415
42. Arumosoye OM, Obriki OD. Systematic review of near-miss and hazard observation data utilization in industrial safety management. Iconic Research and Engineering Journals. 2019; 3(2):981-999. Doi: https://doi.org/10.64388/IREV3I2-1714417
43. Arumosoye OM, Obriki OD. A governance-oriented conceptual model for contractor safety performance in multi-contract industrial projects. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):728-740. Doi: https://doi.org/10.54660/.IJMRGE.2020.1.5.728-740
44. Arumosoye OM, Obriki OD. Organizational learning-based conceptual maturity model for continuous safety performance improvement. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(1):971-988.
45. Arumosoye OM, Obriki OD. Conceptual risk pathway model for lifting and rigging operations in heavy industrial construction. Gyanshauryam, International

Scientific Refereed Research Journal. 2022; 5(5):346-369. Doi: https://doi.org/10.32628/GISRRJ2256237
46. Arumosoye OM, Obriki OD. Conceptual model for emergency response readiness and capability in energy and process facilities. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023; 9(3):897-917. Doi: https://doi.org/10.32628/CSEIT25112791
47. Arumosoye OM, Obriki OD. Conceptual model of safety leadership influence in large temporary project organizations. International Journal of Advanced Multidisciplinary Research and Studies. 2024; 4(6):3034-3047.
48. Asiedu W, Quainoo R. How far can energy harvesting take us? A systematic review of radio frequency strategies for energy autonomous sensing. Shodhshauryam, International Scientific Refereed Research Journal. 2023a; 6(1):448-466.
49. Asiedu W, Quainoo R. Toward maintenance free wireless infrastructure: Simulating performance and reliability in large scale intermittently powered IoT networks. Gyanshauryam, International Scientific Refereed Research Journal. 2023b; 6(1):489-510.
50. Asiedu W, Quainoo R. Rethinking energy, reliability, and latency trade-offs in green communication for next generation IoT. International Journal of Multidisciplinary Research and Growth Evaluation. 2024; 5(6):1987-1994.
51. Atta S, Adjaklo E, Asomani E, Adenuga OM. Advances in welding inspection standards and quality assurance practices in large-scale power generation projects. International Journal of Engineering and Modern Technology. 2022; 8(5):101-124. Doi: https://doi.org/10.56201/ijemt.v8.no5.2022.pg101.124
52. Atta S, Asomani E, Adenuga OM. A systematic review of green corrosion inhibitors from agricultural extracts for mild steel protection in acidic and alkaline media. International Journal of Engineering and Modern Technology. 2018; 4(1):64-97. Doi: https://doi.org/10.56201/ijemt.vol.4.no1.2018.pg64.97
53. Atta S, Tofah P, Adenuga OM. Advances in non-destructive testing methods for weld integrity evaluation in high-capacity power infrastructure. International Journal of Engineering and Modern Technology. 2021; 7(1):20-47. Doi: https://doi.org/10.56201/ijemt.vol.7.no1.2021.pg20.47
54. Atta S, Tofah P, Kankam MA, Adenuga OM. A critical review of NDT-based integrity management and corrosion risk assessment strategies for refinery process equipment. International Journal of Engineering and Modern Technology. 2020; 6(2):19-46. Doi: https://doi.org/10.56201/ijemt.vol.6.no2.2020.pg19.46
55. Bello A, Akomolafe O, Agu MU. A conceptual framework for data-driven procurement risk management in multinational enterprises. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2307-2318.
56. Carbon Trust. Floating Wind Joint Industry Programme: Wet Storage and Quick Connectors, Stage 3 work programme findings, 2024.
57. COREWIND. D2.1 Review of the state of the art of mooring and anchoring designs. EU H2020 project deliverable, 2020.
58. Crowle AP, Thies PR. Floating offshore wind turbines port requirements for construction. Proceedings of the IMechE, Part M: Journal of Engineering for the Maritime Environment, 2022.
59. Dagodzo D. A conceptual framework for UAV integration into national power grid inspection programs. Iconic Research and Engineering Journals. 2018a; 2(5):391-412. Doi: https://doi.org/10.64388/IREV2I5-1716082
60. Dagodzo D. A review of UAV applications in electrical transmission line inspection: Methods, technologies, and challenges. Iconic Research and Engineering Journals. 2018b; 2(6):234-254.
61. Dagodzo D, Ahiaeke Patrick MC, Aliliele C. AI and deep learning for vegetation classification in power corridor management: A review. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2022; 8(6):405-429.
62. Dagodzo D, Ahiaeke Patrick MC. UAV-based pipeline and corridor monitoring: A review of current practices and emerging technologies. Iconic Research and Engineering Journals. 2020; 3(10):574-597.
63. Dagodzo D, Ahiaeke Patrick MC. A review of GIS applications in utility asset management and infrastructure planning. Iconic Research and Engineering Journals. 2021a; 5(3):468-492. Doi: https://doi.org/10.64388/IREV5I3-1716085
64. Dagodzo D, Ahiaeke Patrick MC. An integrated framework for UAV, LiDAR, and GIS in infrastructure corridor management. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2021b; 7(5):497-524. Doi: https://doi.org/10.32628/CSEIT217566
65. Dagodzo D, Ahiaeke Patrick MC. A review of right-of-way encroachment detection methods using geospatial technologies. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2022; 8(4):448-471.
66. Dagodzo D, Ahiaeke Patrick MC. A framework for integrating drone operations into enterprise GIS systems for utility companies. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023a; 9(3):640-665.
67. Dosunmu AA, Ogundele PO. Security audit and enterprise risk assessment frameworks for resilient information systems. Iconic Research and Engineering Journals. 2019; 3(5):434-447. Doi: https://doi.org/10.64388/IREV3I5-1713
68. Dosunmu AA, Ogundele PO. Cyber risk quantification models for prioritizing enterprise security investment decisions. International Journal of Multidisciplinary Research and Growth Evaluation. 2024b; 5(6):1777-1785.
69. Efobi OZ, Akinleye OK, Fasawe O. Conceptual framework for sustainable procurement practices in local manufacturing enterprises in Africa. Gyanshauryam, International Scientific Refereed Research Journal. 2022a; 5(6):447-478.
70. Efobi OZ, Akinleye OK, Fasawe O. Conceptual model for data-driven lean supply chain optimization in manufacturing and retail operations. International Journal of Scientific Research in Computer Science,

Engineering and Information Technology. 2022b; 8(6):479-508.
71. Efobi OZ, Akinleye OK, Fasawe O. Conceptual framework for developing a resilience index for post-pandemic supply chains. Shodhshauryam, International Scientific Refereed Research Journal. 2023; 6(2):421-432.
72. Eyetsemitan RA, Oyeleye AO, Ambali KB, Fadayomi O. Standard operating procedures as strategic assets in small business operations: A systematic review and implementation framework. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(5):436-467.
73. Eze FI, Akinleye OK, Anene UN. Development of a cross-border regulatory harmonization model for African pharmaceutical markets: The ARCH-Model framework. International Journal of Health and Pharmaceutical Research. 2024a; 9(3):44-68.
74. Eze FI, Anene UN, Akinleye OK. Creation of a drug shortage early warning and regulatory response model for essential medicines in global health systems. Research Journal of Pure Science and Technology. 2022a; 5(1):33-55.
75. Eze FI, Anene UN, Akinleye OK. Design of an integrated regulatory readiness maturity model for pharmaceutical companies seeking global market entry. International Journal of Health and Pharmaceutical Research. 2022b; 7(4):12-36.
76. Eze FI, Anene UN, Akinleye OK. Pharmaceutical supply chain governance, environmental risk management, and sustainable access to essential medicines in emerging economies: The PSCG-ERM framework. International Journal of Health and Pharmaceutical Research. 2023; 8(2):55-79.
77. Falegan OC, Aniebonam SO. Conceptual framework for lifecycle risk assessment in offshore produced water management. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(5):322-345.
78. Falegan OC, Aniebonam SO. Integrated physicochemical and bio-based treatment strategies for produced water in arid environments: A review. Gyanshauryam, International Scientific Refereed Research Journal. 2023; 6(1):425-443.
79. Falegan OC, Aniebonam SO. Decentralized produced water treatment systems for remote energy assets: A conceptual design framework. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2024; 10(3):1133-1151.
80. GHD. Port requirements to construct a floating offshore wind farm, 2024. https://www.ghd.com/en/insights/port-requirements-to-construct-a-floating-offshore-wind-farm
81. Ike PN, Ogbuefi E, Nnabueze SB, Olatunde-Thorpe J, Aifuwa SE, Oshoba TO, *et al*. Supplier relationship management strategies fostering innovation, collaboration, and resilience in global supply chain ecosystems. International Journal of Multidisciplinary Evolutionary Research. 2021; 2(2):52-62. Doi: https://doi.org/10.54660/IJMER.2021.2.2.52-62
82. Ike PN, Ogbuefi E, Nnabueze SB, Olatunde-Thorpe J, Aifuwa SE, Oshoba TO, *et al*. Lean supply chain practices improving operational efficiency, reducing waste, and enhancing organizational competitiveness. International Journal of Multidisciplinary Evolutionary Research. 2022; 3(2):61-72.
83. Imenco. Integrated Chain Protection: Clamp and bracket-mounted sacrificial anode technology for mooring chains. Technical product documentation, 2024.
84. Komi NM. Hybrid deep learning for wind power forecasting: From grid stability to market equity for small generators. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):989-1014. Doi: https://doi.org/10.54660/.IJMRGE.2021.2.6.989-1014
85. Komi NM, Adamolekun A. Interpretable machine learning for early failure prediction in distributed renewable energy assets. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):1015-1038. Doi: https://doi.org/10.54660/.IJMRGE.2021.2.6.1015-1038
86. Komi NM, Adamolekun A. Hierarchical, decentralized, or hybrid? A systematic review of control architectures for distributed energy resources. International Journal of Engineering and Modern Technology. 2022; 8(5):141-190.
87. Komi NM, Adeniji IO. A tiered digital twin that brings predictive diagnostics to resource-constrained renewable energy sites. International Journal of Engineering and Modern Technology. 2023; 9(3):287-347. Doi: https://doi.org/10.56201/ijemt.v9.no3.2023.pg287.347
88. Komi NM, Ganiu OS. Grid-connected battery storage in hot and weak-grid regions: Advances, degradation challenges, and lifecycle equity. International Journal of Multidisciplinary Research and Growth Evaluation. 2022; 3(6):1072-1095. Doi: https://doi.org/10.54660/.IJMRGE.2022.3.6.1072-1095
89. Komi NM, Ganiu OS. Edge intelligence for resilient microgrid control: Advances, energy sovereignty, and open challenges. Gyanshauryam, International Scientific Refereed Research Journal. 2023; 6(3):525-586.
90. Kumuyi O, Uzoka E, Akeju B, Ozowara DE. Architecture for machine learning-enabled predictive energy management using IoT sensor networks. International Journal of Advanced Multidisciplinary Research and Studies. 2024; 4(6):3138-3149. Doi: https://doi.org/10.62225/2583049X.2024.4.6.6004
91. Lawal OA, Oduleye TE. A conceptual decision model for capital allocation using financial analytics. Gyanshauryam, International Scientific Refereed Research Journal. 2021a; 4(2):269-295.
92. Li G, *et al*. Reliability analysis of mooring chains for floating offshore wind turbines. Frontiers in Built Environment, Vol. 10, Article 1463682, 2024. Doi: https://doi.org/10.3389/fbuil.2024.1463682
93. Mbonu IS, Iwuanyanwu U, Aliliele C, Uzoka E. A conceptual framework for agile supply chain digital transformation with embedded IT risk and ISO compliance controls. Iconic Research and Engineering Journals. 2020a; 3(9):512-534.
94. Medon JJ, Oduleye TE. An integrated predictive analytics model for enhancing strategic financial forecasting and decision accuracy. Gyanshauryam, International Scientific Refereed Research Journal. 2024; 7(3):258-279.
95. Nnabueze SB, Ike PN, Olatunde-Thorpe J, Aifuwa SE,

Oshoba TO, Ogbuefi E, *et al*. End-to-end visibility frameworks improving transparency, compliance, and traceability across complex global supply chain operations. International Journal of Multidisciplinary Futuristic Development. 2021; 2(2):50-60. Doi: https://doi.org/10.54660/IJMFD.2021.2.2.50-60
96. Obogo SF, Arumosoye OM, Obriki OD. Advances in internal QHSE audit systems for industrial engineering operations. Iconic Research and Engineering Journals. 2020a; 4(4):399-417. Doi: https://doi.org/10.64388/IREV4I4-1715499
97. Obogo SF, Arumosoye OM, Obriki OD. Conceptual risk management model for heavy lifting and crane installation engineering operations. Shodhshauryam, International Scientific Refereed Research Journal. 2020b; 3(4):122-144. Doi: https://doi.org/10.32628/SHISRRJ214441
98. Obogo SF, Arumosoye OM, Obriki OD. Critical review of occupational safety management systems in oil and gas maintenance projects. Shodhshauryam, International Scientific Refereed Research Journal. 2020c; 3(4):145-168.
99. Obogo SF, Arumosoye OM, Obriki OD. Advances in proactive hazard recognition and near miss reporting systems. International Journal of Multidisciplinary Research and Growth Evaluation. 2021a; 2(6):835-846.
100. Obogo SF, Arumosoye OM, Obriki OD. Review of sustainable environmental practices in occupational safety management systems. International Journal of Scientific Research in Civil Engineering. 2024a; 8(3):164-196. Doi: https://doi.org/10.32628/IJSRCE248420
101. Obogo SF, Nwafor MI, Ozobu CO. Conceptual leadership model for safety culture development in construction and engineering projects. International Journal of Scientific Research in Civil Engineering. 2023; 7(6):124-148.
102. Obogo SF, Obriki OD, Arumosoye OM. Conceptual model for incident prevention in industrial maintenance engineering environments. International Journal of Multidisciplinary Research and Growth Evaluation. 2021b; 2(6):847-858. Doi: https://doi.org/10.54660/IJMRGE.2021.2.6.847-858
103. Obogo SF, Obriki OD, Arumosoye OM. Conceptual safety governance model for large commercial facility operations. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(6):383-410.
104. Obogo SF, Ozobu CO, Nwafor MI. Conceptual environmental safety compliance framework for construction and infrastructure projects. International Journal of Scientific Research in Civil Engineering. 2024b; 8(3):132-163. Doi: https://doi.org/10.32628/IJSRCE248419
105. Obogo SF, Ozobu CO, Uduokhai DO. Advances in leadership driven safety culture transformation in large construction workforces. Iconic Research and Engineering Journals. 2019a; 3(5):507-523.
106. Obogo SF, Ozobu CO, Uduokhai DO. Development of a construction safety risk governance model for multi contractor high rise projects. Iconic Research and Engineering Journals. 2019b; 2(9):502-522.
107. Obogo SF, Uduokhai DO, Ozobu CO. Systematic review of hazard identification and risk control practices in urban construction projects. Iconic Research and Engineering Journals. 2019c; 2(12):666-681.
108. Obogo SF, Uduokhai DO, Ozobu CO. Review of contractor safety compliance systems in infrastructure engineering projects. International Journal of Scientific Research in Civil Engineering. 2021c; 5(4):76-100.
109. Obriki OD, Arumosoye OM. Conceptual modeling of data-driven occupational safety risk control in large-scale energy infrastructure projects. Iconic Research and Engineering Journals. 2018; 1(7):169-189. Doi: https://doi.org/10.64388/IREV1I7-1714414
110. Obriki OD, Arumosoye OM. A conceptual framework linking management safety walkthrough frequency and coverage to safety culture outcomes in mega projects. Iconic Research and Engineering Journals. 2019; 2(8):355-374.
111. Obriki OD, Arumosoye OM. Conceptual framework for human error causation in high-risk construction and industrial activities. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):715-727.
112. Obriki OD, Arumosoye OM. Conceptual model for institutionalizing life-preserving safety practices across project-based organizations. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(3):688-706.
113. Obriki OD, Arumosoye OM. Conceptual framework explaining recurrence mechanisms of unsafe behaviors in high-hazard worksites. Shodhshauryam, International Scientific Refereed Research Journal. 2022; 5(3):380-402.
114. Obriki OD, Arumosoye OM. Conceptual framework for proactive hazard identification using digital safety data streams. Gyanshauryam, International Scientific Refereed Research Journal. 2023; 6(3):457-481. Doi: https://doi.org/10.32628/GISRRJ236336
115. Obriki OD, Arumosoye OM. Conceptual governance framework for subcontractor safety performance management. International Journal of Advanced Multidisciplinary Research and Studies. 2024a; 4(6):3020-3033.
116. Obriki OD, Arumosoye OM. Systematic review of incident investigation approaches and prevention-oriented learning in industrial operations. Shodhshauryam, International Scientific Refereed Research Journal. 2024b; 7(4):239-263. Doi: https://doi.org/10.32628/SHISRRJ247163
117. Obriki OD, Arumosoye OM, Obogo SF. Advances in continuous hazard monitoring systems for workplace safety. International Journal of Advanced Multidisciplinary Research and Studies. 2023a; 3(6):2742-2759. Doi: https://doi.org/10.62225/2583049X.2023.3.6.6075
118. Obriki OD, Obogo SF, Arumosoye OM. Advances in workforce safety training models for operational risk reduction. Gyanshauryam, International Scientific Refereed Research Journal. 2022a; 5(6):349-382.
119. Obriki OD, Obogo SF, Arumosoye OM. Review of emergency preparedness and evacuation systems in high density commercial buildings. Gyanshauryam, International Scientific Refereed Research Journal. 2022b; 5(6):411-446.
120. Obriki OD, Obogo SF, Arumosoye OM. Review of behavioral safety programs for risk reduction in large

workforces. International Journal of Advanced Multidisciplinary Research and Studies. 2023b; 3(6):2760-2775.
121. Oduleye TE, Medon JJ. A predictive model for optimizing cash flow and working capital management in corporations. Gyanshauryam, International Scientific Refereed Research Journal. 2023a; 6(5):739-754.
122. Ogunwole O, Okonkwo CS, Agbabiaka J, Mayo W, Okeke OT. Supply chain resilience framework for critical infrastructure and gas processing plants. Shodhshauryam, International Scientific Refereed Research Journal. 2021; 4(4):444-461. Doi: https://doi.org/10.32628/SHISRRJ214462
123. Okojie JS, Filani OM, Ike PN, Okojokwu-Idu JO, Nnabueze SB, Ihwughwavwe SI. Integrating AI with ESG metrics in smart infrastructure auditing for high-impact urban development projects. International Journal of Multidisciplinary Futuristic Development. 2023a; 4(1):32-44. Doi: https://doi.org/10.54660/IJMFD.2023.4.1.32-44
124. Okonkwo CS, Agbabiaka J, Mayo W, Okeke OT. Conceptual framework for digital supply chain governance in energy and infrastructure sectors. Gyanshauryam, International Scientific Refereed Research Journal. 2024a; 7(4):335-356. Doi: https://doi.org/10.32628/GISRRJ247423
125. Okonkwo CS, Agbabiaka J, Mayo W, Okeke OT. Model for predictive procurement planning to sustain operational uptime. International Journal of Scientific Research in Humanities and Social Sciences. 2024b; 1(2):909-928. Doi: https://doi.org/10.32628/IJSRSSH242772
126. Okonkwo CS, Agbabiaka J, Mayo W, Okeke OT. Framework for secure and scalable supply chain systems supporting national energy reliability. International Journal of Advanced Multidisciplinary Research and Studies. 2024c; 4(6):2816-2826. Doi: https://doi.org/10.62225/2583049X.2024.4.6.5494
127. Okonkwo CS, Agbabiaka J, Mayo W, Okeke OT. Review of advances in procurement strategy, ERP adoption, and logistics performance. International Journal of Advanced Multidisciplinary Research and Studies. 2024d; 4(6):2827-2835. Doi: https://doi.org/10.62225/2583049X.2024.4.6.5495
128. Okonkwo CS, Agbabiaka J, Mayo W, Okeke OT. Review of digital supply chain models for cost control and operational continuity. International Journal of Advanced Multidisciplinary Research and Studies. 2024e; 4(6):2836-2846. Doi: https://doi.org/10.62225/2583049X.2024.4.6.5496
129. Okonkwo CS, Agbabiaka J, Ogunwole O, Mayo W, Okeke OT. Model for demurrage elimination and port logistics efficiency in emerging economies. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):552-562. Doi: https://doi.org/10.54660/IJMRGE.2020.1.5.552-562
130. Okonkwo CS, Agbabiaka J, Ogunwole O, Mayo W, Okeke OT. Conceptual model for materials readiness and maintenance-driven supply chain performance. International Journal of Multidisciplinary Research and Growth Evaluation. 2021a; 2(6):584-594. Doi: https://doi.org/10.54660/IJMRGE.2021.2.6.584-594
131. Okonkwo CS, Mayo W, Okeke OT. Conceptual model for asset lifecycle management and inventory visibility. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023; 10(1):809-824. Doi: https://doi.org/10.32628/CSEIT2391568
132. Okonkwo CS, Ogunwole O, Okeke OT. Framework for strategic procurement optimization in oil and gas operations. Iconic Research and Engineering Journals. 2018a; 1(7):153-168. Doi: https://doi.org/10.64388/IREV1I7-1713119
133. Okonkwo CS, Ogunwole O, Okeke OT. Model for inventory availability and plant uptime improvement in energy facilities. Iconic Research and Engineering Journals. 2018b; 2(4):160-172. Doi: https://doi.org/10.64388/IREV2I4-1713120
134. Okonkwo CS, Ogunwole O, Mayo W, Okeke OT. Framework for regulatory-compliant procurement in high-risk energy environments. International Journal of Multidisciplinary Research and Growth Evaluation. 2021b; 2(6):595-605. Doi: https://doi.org/10.54660/IJMRGE.2021.2.6.595-605
135. Okonkwo CS, Ogunwole O, Okeke OT, Mayo W. Conceptual framework for cost reduction through contract negotiation and vendor governance. Iconic Research and Engineering Journals. 2019; 2(9):468-482. Doi: https://doi.org/10.64388/IREV2I9-1713121
136. Okoruwa PO, Babatope OM, Akokodaripon DA, Akinleye OK. Developing integrated digital platforms for enhancing transparency in procurement and supply chain management. International Journal of Multidisciplinary Research and Growth Evaluation. 2024; 5(6):1634-1646.
137. Omoegun GO, Sunday EA, Essien MA, Oluokun OA. Vibration-based condition monitoring of rotating machinery using LabVIEW. International Journal of Scientific Research in Civil Engineering. 2023; 7(6):82-108.
138. Onche VO, Ogbonna CS, Adegbite MP. Effectiveness of cybersecurity awareness training on insider-threat behavior among organizational administrators: An integrative academic review. International Journal of Computer Science and Mathematical Theory. 2024; 10(4):55-88.
139. Oyeleye AO, Eyetsemitan RA, Ambali KB, Fadayomi O. Reducing client onboarding cycle time in small professional services firms: A Lean Six Sigma process redesign framework. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(4):599-628.
140. PPG. Advances in corrosion for offshore wind, including status of the ISO 25249 proposal accepted in 2024, 2024. https://www.ppg.com/en-US/pmc/advances-in-corrosion-for-offshore-wind
141. Rezende F, *et al*. Reliability-based fatigue inspection planning for mooring chains of floating systems. Reliability Engineering and System Safety, Vol. 246, Article 110084, 2024.
142. Rivera Arreba I, *et al*. Mooring System Transport and Installation Logistics for a Floating Offshore Wind Farm in Lannion, France. Journal of Marine Science and Engineering. 2022; 10(10):1354.
143. Sunday EA, Omoegun GO. Smart fault detection in HVAC systems using sensor-based monitoring. International Journal of Scientific Research in Science, Engineering and Technology. 2022; 7(4):380-403.

144. Sunday EA, Omoegun GO, Essien MA, Oluokun OA. Thermodynamic efficiency and control strategies in residential air conditioning systems. International Journal of Scientific Research in Civil Engineering. 2019; 3(5):88-112.
145. Sunday EA, Omoegun GO, Essien MA, Oluokun OA. Transitioning from reactive to predictive maintenance in mechanical systems. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2020; 6(6):425-447.
146. Tonoyan A, Dada O, Ayivi-Donkor SS. Algorithmic process optimization and cost reduction: A review of simulation modeling and financial impact assessment. Journal of Accounting and Financial Management. 2022b; 8(8):130-158.
147. Tonoyan A, Dada O, Ayivi-Donkor SS. Conceptual model for predictive cost optimization: Machine learning applications in business transformation analysis. International Journal of Economics and Business Management. 2022c; 8(6):77-104.
148. Tonoyan A, Dada O, Ayivi-Donkor SS. Advances in supply chain resilience: Predictive models for vendor risk assessment and procurement cost optimization. International Journal of Social Sciences and Management Research. 2024a; 10(11):525-551. Doi: https://doi.org/10.56201/ijssmr.v10.no11.2024.pg.525.551
149. Tonoyan A, Dada O, Ayivi-Donkor SS. Real-time KPI tracking systems: A review of automated performance monitoring and data-driven decision making. World Journal of Innovation and Modern Technology. 2024b; 8(6):247-281.
150. Wang Y, *et al*. Evaluation and Life Extension of Mooring Systems. Proceedings of the 29th International Ocean and Polar Engineering Conference (ISOPE), Paper ISOPE-I-19-539, 2019.
151. World Forum Offshore Wind. Mooring Systems for Floating Offshore Wind: Integrity Management, Mooring Subcommittee White Paper, 2023.
152. Yeboah BK, Ike PN. Programmatic strategy for renewable energy integration: Lessons from large-scale solar projects. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(3):306-315. Doi: https://doi.org/10.54660/.IJMRGE.2020.1.3.306-315
153. Yeboah BK, Enow OF, Ike PN, Nnabueze SB. Program design for advanced preventive maintenance in renewable energy systems. Shodhshauryam, International Scientific Refereed Research Journal. 2024; 7(2):138-156. Doi: https://doi.org/10.32628/SHISRRJ2472156