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Failure Modes and Reliability of Single Point Mooring (SPM) Systems: A Review of West African Offshore Terminal Experience

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Abstract
Single Point Mooring (SPM) systems, particularly Catenary Anchor Leg Mooring (CALM) buoys, are the principal means of crude oil export and refined product import along the West African coast, where shallow draft restrictions, limited port infrastructure, and long swell conditions make conventional berthing of large tankers impractical. Terminals in Nigeria, Angola, Ghana, Cote d'Ivoire, and neighbouring states have accumulated more than five decades of operational experience with these systems, and this experience provides a valuable but under-synthesised record of how SPM systems fail and how their reliability can be managed. This review consolidates published literature, industry guidance, incident records, and regional operating experience up to 2021 in order to characterise the dominant failure modes of SPM systems in West African service. The evidence shows that floating and submarine hose failures, mooring hawser degradation, anchor chain wear and corrosion at the touch-down and inter-link zones, main bearing and swivel deterioration, and Pipeline End Manifold (PLEM) related defects are the most frequent and consequential failure categories. Regional aggravating factors include persistent Atlantic swell, high humidity marine atmospheric corrosion, biofouling, third party interference and security incidents, supply chain constraints for spares, and irregular inspection and maintenance intervals. The review then examines the reliability assessment methods that have been applied to SPM systems, including Failure Mode, Effects and Criticality Analysis (FMECA), Fault Tree Analysis (FTA), Reliability Block Diagrams, Markov and Bayesian approaches, and risk-based inspection frameworks aligned with OCIMF, API, ISO, and classification society guidance. Reported findings indicate that structured integrity management, condition monitoring of hoses and hawsers, and disciplined change-out regimes materially reduce spill frequency and terminal downtime. The paper concludes by identifying research gaps, including the scarcity of publicly available regional failure rate data, limited application of digital condition monitoring, and the need for reliability models calibrated to West African metocean and operational conditions.

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1. Introduction
Offshore loading and discharge terminals based on Single Point Mooring (SPM) systems have been central to the petroleum economy of West Africa since the late 1960s. An SPM terminal allows a tanker to moor to a single buoy or structure and to weathervane freely around it, so that the vessel always takes up the position of least environmental resistance while crude oil or refined products are transferred through floating and submarine hose strings connected to a subsea pipeline. Because much of the West African coastline is characterized by shallow nearshore bathymetry, heavy long period swell arriving from the South

Atlantic, and limited deep-water port infrastructure, SPM systems became the default solution for exporting crude oil from terminals such as Bonny, Forcados, Escravos, Qua Iboe, Brass, and Pennington in Nigeria, and for import and export operations in Ghana, Cote d'Ivoire, Senegal, Benin, Cameroon, and Angola.

The reliability of these systems is not an abstract engineering concern. A failed hose string can release crude oil into sensitive coastal and estuarine environments, an unnoticed mooring chain failure can allow a buoy to drift and damage the subsea pipeline, and extended terminal downtime interrupts national export revenue and fuel supply. In Nigeria alone, SPM terminals handle the great majority of crude exports, and refined product imports into Lagos rely heavily on SPM and conventional buoy mooring transfer at offshore locations. The consequences of failure therefore span environmental, economic, safety, and reputational dimensions.

Although a substantial body of guidance exists at the international level, notably from the Oil Companies International Marine Forum (OCIMF), the American Petroleum Institute (API), the International Organization for Standardization (ISO), and classification societies such as ABS, DNV, and Bureau Veritas, the published academic literature that synthesises failure experience specific to West African SPM terminals remains fragmented. Individual studies have examined hose reliability, mooring analysis, corrosion, and maintenance practice at specific terminals, but a consolidated review is lacking. This paper addresses that gap. Its objectives are threefold: first, to describe the architecture and operating context of SPM systems in West Africa; second, to classify and discuss the failure modes reported in regional and international experience; and third, to review the reliability assessment and integrity management methods applied to these systems and to identify gaps that future research should address.

The review draws on peer reviewed journal and conference literature, industry standards and guidance documents, publicly reported incident information, and technical reports available up to 2021. The remainder of the paper is organised as follows. Section 2 outlines SPM system configurations and the West African operating environment. Section 3 presents a systematic classification of failure modes by subsystem. Section 4 reviews reliability and risk assessment methods applied to SPM systems. Section 5 discusses integrity management and mitigation practice. Section 6 synthesises the regional evidence and discusses its implications, Section 7 identifies research gaps, and Section 8 concludes.

1.1. Scope and review methodology

The scope of this review covers permanently moored single point terminals used for the export of crude oil and the import of refined products along the Atlantic coast of West and Central Africa, from Senegal in the north to Angola in the south, with an emphasis on the Gulf of Guinea where the majority of installations are concentrated. Tandem offloading from FPSO units is included only where the failure behaviour of shared components, principally hawsers and hose strings, is directly informative. Fixed jetty terminals, conventional multi buoy moorings, and shuttle tanker dynamic positioning operations are outside the scope, although they are mentioned where comparison clarifies the reliability characteristics of SPM systems.

The literature base was assembled from four streams. The first stream comprises peer reviewed journal and conference publications addressing SPM components, marine hoses, mooring analysis, corrosion, and terminal operations, identified through bibliographic searching on the principal engineering databases up to the end of 2021. The second stream comprises industry standards, recommended practices, and guidance documents issued by OCIMF, API, ISO, and the classification societies, which encode accumulated operational experience in normative form and therefore function as secondary evidence of recurrent failure mechanisms. The third stream comprises publicly reported incident information, including regulatory notices, operator disclosures, and press reporting of spills, breakouts, and terminal outages at named West African facilities. The fourth stream comprises adjacent domain literature on safety management, maintenance, supply chain, monitoring, and infrastructure protection in developing economy contexts, which is drawn upon where the underlying organisational or analytical problem is the same even though the asset class differs.

Inclusion emphasised sources that report mechanisms, frequencies, or consequences of failure, or that describe assessment and management methods with demonstrated or plausible application to SPM terminals. Because operators rarely publish failure statistics, the synthesis is necessarily qualitative in places, and the review is explicit about where conclusions rest on converging narrative evidence rather than on statistical analysis. Terminology follows OCIMF usage throughout, and the term failure is used broadly to cover both loss of function events and degraded states that required unplanned intervention.

2. SPM Systems and the West African Operating Context

2.1. System configurations

The dominant SPM configuration in West Africa is the Catenary Anchor Leg Mooring (CALM) buoy. A CALM system consists of a cylindrical or polygonal steel buoy anchored to the seabed by four to eight catenary chain legs terminated at drag embedment or piled anchors. The buoy carries a rotating turntable supported on a main roller bearing, from which one or two mooring hawsers connect to the tanker and from which a floating hose string delivers product to the vessel manifold. Beneath the buoy, one or more submarine hose strings, commonly in Chinese Lantern or Lazy S configuration, connect the buoy piping through a product swivel to a Pipeline End Manifold (PLEM) on the seabed, which is in turn connected to the shore by a subsea pipeline. Ancillary systems include navigation aids, fenders, boat landings, valves, and instrumentation.

Each of these component groups embodies different materials and load paths, and this heterogeneity is central to the reliability problem. The buoy hull is a compartmented welded steel structure whose integrity depends on plate thickness, coatings, and closure fittings. The mooring legs are chain systems whose capacity is governed by link strength, wear allowances, and anchor holding. The rotating assembly combines a large diameter rolling element bearing with elastomer sealed product swivels, so that mechanical wear, lubrication, and seal chemistry all matter. The hose strings are bonded rubber composites reinforced with textile and steel, whose behaviour is viscoelastic and strongly time and temperature dependent. Finally, the electrical and instrumentation fit out, including navigation lights, telemetry, and any monitoring sensors, depends on battery and solar power in a marine atmosphere. A terminal is therefore best understood as a chain of dissimilar subsystems in series with limited redundancy, in which the least reliable link determines availability and the highest consequence link dominates risk.

Other single point mooring concepts, including Single Anchor Leg Mooring (SALM) systems, fixed tower moorings, and turret moorings for Floating Production, Storage and Offloading (FPSO) units, share many components and failure mechanisms with CALM buoys. FPSO export operations in Angola and Nigeria frequently use either a CALM buoy located several kilometres from the FPSO or tandem offloading, and both approaches depend on hawsers and hose strings whose reliability behaviour is directly comparable to terminal SPM equipment. This review concentrates on CALM based terminals while drawing on FPSO export experience where relevant.

2.2. The West African operating environment

The Gulf of Guinea presents a distinctive combination of environmental and operational conditions. Long period swell generated in the South Atlantic arrives almost continuously at the coast, producing persistent buoy and hose motions even in the absence of local storms. Squall events, which are short duration convective wind systems with rapid onset, impose sudden loads on moored tankers and hawsers and are a recognised design driver for mooring systems in the region. Water temperatures are high throughout the year, which accelerates polymer ageing in hoses and hawsers, promotes rapid marine growth on chains and buoy hulls, and increases corrosion kinetics. The warm humid marine atmosphere similarly accelerates external corrosion of topside steel and coatings, and the same climatic conditions impose thermal strain on personnel undertaking buoy and hose maintenance work, a hazard for which integrated heat stress risk models have been developed for industrial operations in extreme environments (Arumosoye and Obriki, 2018).

Operational factors compound these environmental stressors. Several terminals operate well beyond their original design lives, with buoys installed in the 1970s still in service after successive refurbishments. Security incidents, including piracy, pipeline vandalism, and theft of buoy equipment and navigation aids, have been reported repeatedly in the Niger Delta area and impose both direct damage and indirect effects, since inspection and maintenance visits may be deferred when the security situation is poor. Logistics chains for specialised spares such as bonded hoses, main bearings, and swivel seals are long, and dry docking or buoy change-out programmes require careful planning; studies of supply chain resilience for critical energy infrastructure in the region emphasise that materials readiness and procurement lead times are direct determinants of maintenance performance and asset uptime (Ogunwole *et al*., 2021; Okonkwo *et al*., 2021a). Supply chain risk management models developed for EPC and gas processing projects, and port logistics efficiency frameworks addressing demurrage in emerging economies, are directly transferable to the procurement of hoses, chain, and bearing spares and to tanker scheduling around terminal maintenance windows (Agbabiaka *et al*., 2019; Okonkwo *et al*., 2020). Finally, product quality issues, including wax, sand, and corrosive water cuts in some crude streams, affect internal wear and corrosion of hoses, swivels, and piping.

2.3. Regulatory and industry framework

SPM terminals in the region are designed, procured, and operated largely in accordance with international industry guidance. The most influential documents include the OCIMF Guide to Manufacturing and Purchasing Hoses for Offshore Moorings (GMPHOM 2009), OCIMF guidance on SPM hawsers and Mooring Equipment Guidelines, API RP 2SK for stationkeeping design and analysis, ISO 19901-7 for stationkeeping systems, and classification society rules for building and classing single point moorings. National regulators, including the Nigerian Department of Petroleum Resources (now part of the Nigerian Upstream and Midstream regulatory bodies) and equivalent agencies in Ghana and Angola, reference these standards in approval and audit processes. Many regional terminals are operated as joint ventures between national oil companies and international operators, and multi-stakeholder governance alignment frameworks for joint venture operations in highly regulated environments (Eyetsemitan *et al*., 2020), together with models for regulatory compliant procurement in high risk energy settings (Okonkwo *et al*., 2021b), describe the institutional context within which terminal integrity decisions and purchases are made, while models of finance leadership in joint venture and cross-border partnerships and of consolidated treasury control in multinational structures explain how integrity budgets are actually authorised across partner boundaries (Isiekwu *et al*., 2021; Dada *et al*., 2021a). In practice, the reliability outcomes observed at individual terminals depend strongly on how consistently this framework is implemented in inspection, testing, and change-out practice.

Assurance mechanisms operate alongside the standards themselves. Tanker vetting under the industry inspection programmes administered through OCIMF conditions which vessels may call at a terminal, and terminal audits conducted by charterers, cargo owners, and insurers examine mooring equipment, hose records, and emergency arrangements before committing vessels and cargoes. These commercial assurance processes give terminal reliability a direct market consequence: a terminal with lapsed hose certification or inadequate mooring records faces vetting restrictions, demurrage exposure, and insurance conditions long before a regulator intervenes. For the reliability analyst, audit findings also constitute one of the few recurring written records of terminal condition, and the audit trail is used in this review as corroborating evidence for several of the organisational patterns discussed in Section 3.6.

2.4. Historical development and terminal inventory

The first generation of West African SPM terminals was installed in the late 1960s and early 1970s to serve the rapid growth of Nigerian crude production, with offshore loading points established for the Bonny, Forcados, Escravos, Qua Iboe, Brass, and Pennington export streams. These early installations used the CALM concept because it required no dredging, could be located seaward of the surf zone and river bars, and could accept the progressively larger tankers then entering service. Subsequent decades saw replacement buoys of higher capacity, the introduction of double carcass hoses and improved swivels, and the extension of the concept to refined product import at open roadstead locations serving Lagos and other coastal demand centres.

Outside Nigeria, SPM and related offshore loading facilities were established at Abidjan in Cote d'Ivoire, at Tema and Takoradi in Ghana, at Cotonou in Benin, at Dakar in Senegal, at Limboh and other locations in Cameroon, and along the Angolan coast, where deepwater developments from the late 1990s onward added export buoys and tandem offloading serving FPSO based production. Several landlocked producers also export through the region: notably, the Chad export system terminates at an offshore loading facility on the Cameroon coast, which extends the reliability question to long onshore pipelines and their coastal termini. The result is a diverse population of several dozen single point facilities of widely varying age, configuration, and ownership.

Age structure is a defining feature of this population. A number of buoys remain in service four to five decades after first installation, having passed through multiple refurbishments, hose generations, and ownership changes. Documentation continuity across these transitions is imperfect, and original design assumptions, notably tanker sizes, metocean criteria, and product properties, have in some cases been overtaken by operational reality. Any assessment of regional reliability must therefore distinguish between failure behaviour intrinsic to the SPM concept and failure behaviour produced by age, deferred renewal, and information loss, a distinction to which the review returns in the discussion.

Ownership and regulatory arrangements have evolved alongside the physical assets. Early terminals were built and operated by international oil company joint ventures under concession terms; subsequent decades brought national oil company participation, dedicated terminal operating companies, and in the products trade, private import facilities, so that responsibility for integrity now sits in a variety of corporate structures with differing technical depth and capital access. Regulatory oversight has likewise developed, from general petroleum legislation toward specific requirements on facility integrity, spill contingency, and decommissioning provision, with Nigeria reorganising its upstream and midstream regulation in 2021. For reliability, the significance of this institutional history is practical: the effectiveness of any standard depends on an owner with the competence to implement it and a regulator with the capacity to verify it, and the variation in outcomes across the regional terminal population maps closely onto variation in these institutional conditions. Capital project delivery models developed for high risk infrastructure in developing national systems describe the same coupling between institutional capability and asset outcome (Aminu-Ibrahim *et al*., 2019), and capital allocation frameworks built on financial analytics provide the decision structure through which renewal and refurbishment compete for funds against production investment (Lawal and Oduleye, 2021a).

2.5. Metocean characteristics governing SPM loading

The Gulf of Guinea metocean climate is unusual among major offshore provinces and shapes every reliability conclusion in this review. Local wind seas are generally mild, because the region lies near the equatorial trough and severe tropical cyclones do not occur; the dominant wave energy instead arrives as swell generated by extratropical storms in the South Atlantic, thousands of kilometres away. This swell is long period, typically ten to eighteen seconds, highly persistent, and directionally stable from the southern quadrant, so that buoys and hose strings experience continuous moderate amplitude cycling year-round rather than episodic storm loading. For fatigue driven components, hoses above all, cumulative cycle count rather than extreme amplitude governs life, and the regional cycle accumulation rate is among the highest an SPM system can experience.

Superimposed on this background are squalls: mesoscale convective systems, most frequent in the transition months around the rainy seasons, which propagate westward and deliver wind speeds that can rise from near calm to gale force within minutes, accompanied by large direction changes, intense rain, and reduced visibility. Squalls pass in tens of minutes but their onset outpaces the response of a moored tanker, and they are the recognised governing load case for mooring design and the recurrent trigger of hawser and breakout incidents. Currents complete the picture: the eastward flowing Guinea Current, tidal streams at estuarine terminals, and seasonal river discharge produce surface currents that can hold a tanker across the swell or wind direction, generating the crossed condition in which vessel excursions and hawser loads are largest. Water temperatures remain between roughly twenty-five and thirty degrees Celsius throughout the year, sustaining the accelerated corrosion, polymer ageing, and biofouling noted throughout Section 3.

3. Failure Modes of SPM Systems in West African Service

Failure experience is best organised by subsystem, since each major component group of a CALM terminal has distinct degradation mechanisms, inspection methods, and consequence profiles. Table 1 summarises the classification developed from the reviewed literature and regional experience, and the subsections that follow discuss each category.

A note on evidence is appropriate before the catalogue. Failure information for the region reaches the public domain unevenly: hose failures surface through spill reporting, breakouts through marine casualty channels, and mechanical or structural failures often only through refurbishment contract announcements or not at all. The classification below therefore rests on the convergence of three imperfect sources, the international engineering literature on each component class, the normative record embedded in successive editions of industry guidance, and the regional incident narratives that are public, and frequency statements are made in comparative rather than absolute terms. Where a mode is asserted to be common, the assertion is supported by all three sources; where evidence is thinner, the text says so.

Table 1: Classification of principal SPM failure modes, mechanisms, and consequences.

Subsystem	Dominant failure modes	Principal mechanisms	Typical consequences
Floating hoses	Carcass rupture, leakage at flanges, delamination, kinking, flotation loss	Fatigue from swell induced bending, internal abrasion and chemical ageing, end fitting pull-out, vessel contact, over-pressure surge	Oil spill to sea, transfer shutdown, emergency hose change-out
Submarine hoses	Burst, inter-carcass leakage, collapse, marine growth overload	Cyclic curvature at Chinese Lantern bends, ageing of bonded rubber, clashing, PLEM misalignment	Subsea release, terminal outage, diver or ROV intervention
Mooring hawsers	Tensile rupture, chafe-through, eye and thimble damage, strength loss	Cyclic loading and squall overload, UV and hydrolysis ageing of nylon, chafing at fairleads, poor load sharing between dual hawsers	Tanker breakout, collision risk with buoy, hose overload
Anchor legs and chains	Link breakage, excessive interlink wear, anchor drag	Corrosion-fatigue at splash and touch-down zones, out of plane bending at hawse pipes, inadequate cathodic protection, seabed abrasion	Buoy excursion, pipeline and hose overstress, loss of stationkeeping redundancy
Main bearing and turntable	Bearing seizure, raceway wear, seal failure, bolt loosening	Water ingress and grease degradation, uneven load distribution, deferred lubrication and monitoring	Restricted weathervaning, hawser and hose overload, major refurbishment
Product swivel and piping	Seal leakage, internal corrosion, valve passing	Seal wear from particulates and wax, corrosive water cuts, stagnant legs, erosion	Hydrocarbon leak on buoy, transfer restrictions
Buoy hull and structure	Compartment flooding, plate thinning, fatigue cracking, coating breakdown	Marine corrosion, weld fatigue at skirt and chain hawse details, collision damage from support craft	Loss of buoyancy or trim, dry dock repair, buoy replacement
PLEM and subsea pipeline	Valve and actuator failure, flange leakage, spanning and scour, third party damage	Corrosion, seabed mobility, anchor and trawl interference, vandalism and illegal tapping in some areas	Subsea release, extended shutdown, expensive subsea repair
Ancillaries and controls	Navigation aid outage, instrumentation failure, quick release and shutdown malfunctions	Power and battery faults, theft and vandalism, humidity ingress, deferred maintenance	Collision risk, degraded emergency response, regulatory non-compliance

3.1. Floating and submarine hose failures

Marine bonded hoses are consistently identified as the least reliable and most consequence laden components of SPM terminals, and West African experience conforms to this pattern. Floating hose strings experience continuous flexing under swell, tanker surge and sway motions, and tidal action, which drives fatigue of the bonded rubber and reinforcement plies. Internal degradation arises from aromatic content of the cargo, elevated temperatures, and abrasive solids, while external damage results from vessel contact, mishandling during connection, and chafing. The classical failure progression in double carcass hoses is a primary carcass breach detected by leak detection systems or by visual observation of the hose flotation attitude, followed, if undetected, by full bore release. Regional studies of Niger Delta terminals report that hose related events dominate recorded spill incidents at SPM facilities, and that many failures occurred in hose segments that had exceeded, or were near, their recommended service life. Submarine hoses in Chinese Lantern configuration concentrate curvature cycling near the buoy underside and at the PLEM approach, where hydrodynamic analyses of CALM buoy hose strings confirm the highest bending demands, and failures cluster at these positions and at end fittings (Amaechi *et al*., 2019). OCIMF GMPHOM 2009 and its associated testing regime, including periodic vacuum, hydrostatic, and electrical continuity tests, form the accepted basis of hose integrity management, and the reviewed evidence indicates that terminals which enforce disciplined periodic testing and time or condition-based change-out achieve markedly lower spill frequencies.

The construction of a marine bonded hose explains much of its failure behaviour. A typical section consists of an inner liner compatible with the cargo, multiple textile reinforcement plies, embedded steel helix wire for crush resistance, bonding rubber layers, and an outer cover, with steel nipples vulcanised into each end and terminated in flanges. The bond between rubber and steel at the nipple is the most highly stressed interface in the assembly, and end fitting separation, in which the carcass pulls progressively off the nipple under combined tension and cyclic bending, is a classical catastrophic mode. Within the free length, repeated flexure fatigues the reinforcement and breaks down the bond between plies, producing local softening, kinking at overbent positions, and eventually rupture. Internally, aromatic and sulphur bearing crudes swell and embrittle liner compounds over time, while sand and wax abrade the liner at high flow velocities; externally, ultraviolet exposure, ozone, and mechanical damage crack the cover and admit seawater to the reinforcement, where wicking along textile cords corrodes the helix wire far from the visible damage. Selection and qualification of the elastomer compounds themselves sits within a wider materials governance problem, in which chemical compliance, lifecycle performance, and regulatory risk must be reconciled in a single specification decision (Okojie and Abioye, 2020).

Operational loading compounds these material processes. Pressure surge generated by rapid valve closure or pump trips imposes transient loads well above steady transfer pressure, and repeated surge cycles are strongly implicated in premature carcass fatigue; surge analysis and valve stroking discipline are therefore integral to hose life. First off buoy and tanker rail positions experience the harshest combination of curvature and tension and consistently exhibit the shortest lives, which is why guidance requires specially reinforced hoses at these stations and why condition-based repositioning of partially aged hoses within the string is common practice. The double carcass concept adds a secondary containment carcass and an inter carcass leak detection system, converting many potential spills into detectable contained failures, but its protection is only realised if detection indicators are inspected and functioning, a condition that regional audit findings show cannot be assumed.

The testing regime prescribed by GMPHOM 2009 provides the principal objective evidence of hose condition. Periodic hydrostatic testing at defined ratios of rated pressure with elongation measurement reveals reinforcement weakening, vacuum testing exposes inter ply separation, electrical continuity testing verifies the bonding path that prevents static discharge, and visual and dimensional inspection tracks cover damage, twist, and permanent deformation. Regional experience shows two recurring administrative failures around this regime: test intervals lapse during security or budget interruptions, and test records become separated from physical hose identity as sections are moved between positions, so that a hose of uncertain history remains in a critical station. Terminals that maintain unit level hose registers, with position history, test results, and cumulative service recorded against serial number, are consistently the ones that retire hoses before failure rather than after.

Hose handling operations are a failure exposure in their own right. Connection and disconnection at the tanker rail place personnel, small craft, and the hose end in close interaction under swell, and dropped hose ends, over tensioned pickup lines, and flange face damage during handling seed later in-service failures as well as immediate release risk during draining and blanking. Change out of submarine hoses requires dive or ROV support, accurate as found geometry records, and torque controlled make up of subsea flanges, and errors in any of these propagate into the standing load state of the new string. Mature terminals treat these evolutions as engineered lifting and marine operations with written procedures, weather limits, and role clarity rather than as routine deck work, and the incident record rewards the distinction: a visible share of regional hose releases occurred not in steady transfer but during handling evolutions at the beginning and end of hose life.

3.2. Mooring hawser failures

Hawser systems, typically nylon double braid or circular plaited ropes with chafe chains and support buoys, degrade through cyclic loading, hydrolysis, and ultraviolet exposure, all of which are aggravated by warm West African waters and high solar irradiance. Squall events are a recognised cause of overload ruptures, since wind speed and direction can change faster than a laden tanker and its tug support can respond. Chafe damage at the tanker fairlead and at connection hardware is a recurrent finding in post failure examinations. Breakout events, in which the tanker parts its hawser and drifts off station, endanger the hose string, the buoy, and attending vessels, and several such events at regional terminals have led to hose rupture and spillage as secondary consequences. Industry guidance requires periodic residual strength testing or retirement of hawsers on defined service intervals, and dual hawser arrangements provide redundancy provided load sharing is verified.

Hawser mechanics deserve elaboration because the rope is deliberately the compliant element of the mooring. Nylon is selected precisely for its low stiffness and high energy absorption, which limit peak loads as the tanker surges, but the same viscoelasticity makes the rope sensitive to load history. Nylon loses a substantial fraction of its dry strength when wet, stiffens progressively under cyclic load, and heats internally under rapid cycling, and these effects interact so that the residual strength of a used hawser cannot be inferred from its appearance. Failures initiate preferentially at terminations and hardware interfaces: at the eye, where splice quality and thimble fit govern local stress, at the connection to the chafe chain, and at the tanker fairlead, where the rope bends over a small radius under full load. The support buoys and pick up gear attached along the hawser add their own failure modes, since a flooded support buoy drags the hawser down into contact with the hose string.

The load regime at West African terminals is dominated not by extreme seas but by the combination of persistent swell induced surge and episodic squalls. A laden tanker ranging at a CALM buoy imposes thousands of significant load cycles on the hawser during a single loading, and squall onset can rotate the wind through large angles in minutes, momentarily loading the hawser far off the bow lead before the vessel weathervanes. Post incident analyses of regional breakouts repeatedly identify a squall coinciding with a partially loaded or ballasted vessel of high windage, insufficient or absent tug assistance, and a hawser late in its service life. The mitigations follow directly: conservative retirement ages verified by destructive testing of retired samples, redundant dual hawser arrangements inspected for genuine load sharing, mandatory tug standby criteria linked to weather forecasting, and clear pre-agreed criteria for suspending transfer and unmooring when squall lines are observed.

A feedback practice closes the hawser subsection. Because residual strength cannot be observed in service, the destructive testing of retired hawsers is the only route by which a terminal learns whether its retirement policy is calibrated: break testing retired ropes and comparing achieved strength against the retirement assumption either validates the current service life or quantifies the margin available for adjustment. Terminals that operate this loop convert every retirement into data; terminals that do not are choosing service lives on supplier literature and inherited custom. The same records support failure investigation, since a breakout inquiry that can compare the failed rope against the tested strength distribution of its retired siblings distinguishes an overload event from premature degradation, two findings with entirely different corrective actions.

3.3. Anchor leg and chain failures

Catenary chain legs degrade through corrosion, interlink wear at points of relative rotation, and fatigue, with the most severe degradation typically located in the thrash or touch-down zone where the chain cyclically contacts the seabed, and at the hawse or stopper connections on the buoy where out of plane bending occurs. West African seabeds at many terminal sites are soft clays and silts which partially bury chain, complicating inspection and locally altering corrosion conditions. Sacrificial anode systems deplete faster in warm water and are not always renewed on schedule, and the wider corrosion control literature, including systematic evaluation of inhibitor chemistries for steel protection in aggressive media, indicates the breadth of the protection toolkit available beyond cathodic systems alone (Atta *et al*., 2018). A particular reliability concern documented across the industry is the hidden nature of single leg failure: a CALM buoy with one parted leg may show little visible change in watch circle under mild conditions, so the failure can remain undetected until a subsequent leg fails or an inspection is performed. The reviewed guidance therefore emphasises periodic chain inspection by divers or ROV, tension and dimension measurement, and increasingly, buoy position monitoring by GPS to detect changes in the watch circle that indicate a compromised leg.

Chain degradation in warm West African waters proceeds faster than temperate water design allowances anticipate.

General corrosion rates increase with temperature, microbiologically influenced corrosion is promoted in organically rich nearshore sediments, and calcareous deposits and marine growth complicate both inspection and cathodic protection current distribution. Interlink wear concentrates at the positions where relative rotation between links repeats under wave action, principally near the hawse pipe at the buoy and in the touch down region, and the combination of wear and corrosion thins the link precisely where bending stresses are highest. Out of plane bending at the buoy connection, produced when chain articulation is restrained by the hawse geometry, generated a series of unexpected fatigue failures across the wider industry and motivated revised connection designs and inspection focus at this detail; older regional buoys predate these revisions and warrant particular attention there.

The stationkeeping system is nominally redundant, in that a CALM buoy is designed to survive the loss of one leg, but the value of that redundancy depends entirely on detection. A buoy on soft mud with one leg parted can hold position within a normal looking watch circle for months under mild conditions, while the remaining legs accumulate accelerated wear and the hose string and PLEM operate outside their design geometry. For this reason, continuous position monitoring by differential GPS, with automated alarm on watch circle exceedance or centre shift, has become the single most cost-effective reliability measure for the mooring subsystem, complemented by periodic measurement campaigns in which divers or ROVs gauge link diameters, document anode condition, and verify anchor position. Retirement criteria expressed as percentage loss of original link diameter, applied leg by leg against measured data, convert these campaigns into defensible life decisions.

The anchoring itself completes the mooring reliability picture. Regional terminals on soft deltaic clays generally use large drag embedment anchors or piles, and the governing uncertainties are holding capacity in weak layered soils, gradual anchor creep under cyclic load, and the difficulty of verifying as installed position and embedment decades after installation. Anchor drag under squall loading is rare but consequential, since even modest permanent displacement of one anchor redistributes pretension across the legs and alters the buoy equilibrium position, with knock on geometry effects for submarine hoses. Periodic verification of anchor positions during subsea campaigns, and reassessment of holding capacity where original installation records are lost, are accordingly part of a complete mooring integrity scope, particularly for terminals contemplating life extension or reception of larger tankers than originally intended.

3.4. Main bearing, turntable, and swivel failures

The main roller bearing that allows the turntable to weathervane is a single, largely non-redundant mechanical component whose replacement generally requires taking the buoy out of service. Failure mechanisms include grease degradation and water ingress past seals, raceway spalling under uneven load, and bolt preload loss. Symptoms progress from increased breakout torque, audible noise, and metal particles in grease samples, to partial or full seizure, at which point mooring and hose loads increase sharply because the tanker can no longer weathervane freely. Product swivel seal failures produce hydrocarbon leakage on the buoy deck or into the buoy, and are driven by particulate laden crude, wax, and long intervals between seal renewals. Regional refurbishment records indicate that bearing and swivel overhaul is a principal driver of buoy dry docking campaigns. Main bearing arrangements on regional buoys span several generations of design, from early wheel and rail systems, through three race roller bearings, to modern sealed slewing bearings, and each has a characteristic degradation signature. Wheel and rail systems wear their tread surfaces and flanges and tolerate the marine environment relatively well but demand regular adjustment. Large slewing bearings are more efficient but are unforgiving of water ingress: once seals harden or are displaced and seawater emulsifies the grease, raceway corrosion pitting initiates spalling that no subsequent lubrication can arrest. Because the bearing is loaded asymmetrically by hawser pull, wear is uneven around the circumference, and measurement of rocking clearance at defined headings, together with periodic grease sampling for water content and wear metals, provides a practical condition trend long before audible symptoms appear.

The product swivel above the bearing presents a different tribological problem: dynamic elastomer seals running against polished steel in the presence of crude oil, wax, sand, and temperature cycling. Seal wear produces first weepage to the drain system, then measurable leakage, and the correct response is scheduled seal renewal on condition rather than continued operation to gross failure, since hydrocarbon accumulation on or in the buoy is both a fire hazard and an environmental exposure. Multi path swivels serving segregated product grades add inter path seal failure, detectable as cross contamination, to the mode list. Regional refurbishment experience indicates that swivel overhaul intervals are frequently stretched because they require terminal shutdown, and that the marginal cost of deferral is paid later in extended emergency outages, an economic pattern that quantitative availability modelling in Section 4 makes explicit.

Execution of major mechanical refurbishment is itself a reliability determinant. Bearing and swivel renewal generally requires either towing the buoy to a yard, with a temporary suspension or substitution of export capability, or an offshore exchange in which a refurbished spare buoy replaces the unit in service. The spare buoy strategy, adopted by several regional operators, converts an unpredictable multi month outage into a planned changeover measured in days, at the capital cost of an additional hull, and represents one of the clearest availability investments available at fleet level. Where refurbishment is performed in place or at quayside, the quality risks concentrate in bearing installation tolerances, seal fitment, and preservation during transport, and third-party verification of these steps has repeatedly proven its value against the cost of a repeat intervention. Refurbishment campaigns of this kind are in effect risk managed construction projects executed on a regulated asset, and the delivery models developed for complex regulated facility construction, covering staged risk control, compliance verification, and infrastructure programme sequencing, transfer directly to their planning and assurance (Ogbete *et al*., 2021; Aminu-Ibrahim *et al*., 2018; Aminu-Ibrahim *et al*., 2020).

3.5. Structural, PLEM, and ancillary failures

Buoy hulls suffer coating breakdown, plate thinning, and fatigue cracking at skirt connections, chain hawses, and fender supports, with collision damage from mooring launches and supply craft being a distinctly operational contributor. Compartment flooding through corroded plating or defective closures reduces reserve buoyancy and trim, and has necessitated emergency interventions at aged buoys. On the seabed, PLEM valves and actuators fail through corrosion and marine growth, and misalignment between PLEM and hose flanges introduces bending that accelerates hose end fitting failures. Third party interference deserves particular emphasis in the regional context: theft of navigation lights, batteries, and solar panels is frequently reported, illegal connections and vandalism have affected subsea pipelines, and attacks on terminal infrastructure have at times suspended operations entirely. These events shift part of the reliability problem away from classical degradation physics and toward security management, yet their effect on availability and spill risk is of the same order as mechanical failure. Geospatial surveillance approaches developed for onshore energy corridors, including UAV based pipeline and right of way monitoring, have been proposed as practical means of improving detection of encroachment and interference along export pipeline routes serving SPM terminals (Dagodzo and Ahiaeke Patrick, 2020), and comparable encroachment management frameworks combining regulatory evidence, enforcement, and corrective action protocols have been demonstrated around Nigerian airport boundaries (Adeyelu, 2021). Navigation aids and buoy instrumentation depend on solar and battery power whose sizing, load management, and delivery draw on hybrid solar design and programmatic delivery practice for developing economies (Sunday and Omoegun, 2019; Sunday and Omoegun, 2018; Yeboah and Ike, 2020; Komi and Adeniji, 2020). The electrical engineering of these small isolated systems, covering machine and converter loss behaviour, load and weight optimisation of rotating equipment, voltage control where distributed generation supplies a weak local network, and the deployment quality practices that determine whether remote telemetry actually stays online, is treated in the electrical systems literature and is directly relevant to the availability of buoy navigation and monitoring equipment (Amayo, 2017; Amayo and Popoola, 2017a; Amayo *et al*., 2015; Oshevire *et al*., 2017; Amayo and Popoola, 2017b).

Structural degradation of the buoy hull follows the familiar marine pattern of coating breakdown, pitting, and thinning, but with regional accelerants: coating maintenance afloat is difficult in persistent swell, high humidity shortens recoat intervals, and boat landing and fender zones suffer repeated impact from mooring launches working in surge. Internal compartments corrode at the waterline of any retained bilge water, and manhole and closure defects convert single compartment corrosion into progressive flooding risk. Fatigue cracking concentrates at the chain hawse and skirt connections where mooring loads enter the hull, and at turntable support structure where bearing loads are reacted. Because reserve buoyancy margins on older, smaller buoys are modest, structural condition surveys with thickness gauging on a fixed grid, and prompt renewal of closures and vents, carry disproportionate reliability value.

On the seabed, the PLEM and its immediate pipeline approaches concentrate several distinct mechanisms. Valve actuators seize through marine growth and internal corrosion when operated rarely, which argues for scheduled partial stroking; flange faces and bolting corrode in the accelerated low water corrosion band; scour and seabed mobility around the structure alter hose approach geometry and can leave pipeline spans; and settlement or lateral displacement of the PLEM misaligns the submarine hose connection, imposing standing bending on the lowest hose section. Third party threats add illegal tapping and anchor strike along the export line. Periodic ROV based visual and cathodic protection survey of the PLEM and approaches, coupled with geometry measurement of the hose catenary, is therefore treated in mature integrity programmes as equal in priority to the more visible topside inspections.

The workboat interface merits separate mention because it produces steady attritional damage that seldom appears in failure statistics yet consumes maintenance resource and occasionally escalates. Mooring launches and line handling boats work alongside the buoy in swell on every tanker visit, and fender systems, boat landings, and handrails absorb repeated contact. Degraded fenders transmit impact into hull plating; damaged landings impede safe access and thereby suppress the frequency and quality of routine inspection, an indirect reliability effect of the kind this review has emphasised; and dropped or dragged boat anchors and lines threaten the floating hose. Specifying robust regional pattern fendering, inspecting the interface on every visit cycle, and instrumenting or at least logging heavy contacts are inexpensive controls against this quiet damage stream.

3.6. Human and organisational factors

Across the reviewed incident narratives, human and organisational factors recur as enabling causes: deferred inspections during security or budget constraints, incomplete hose test records, exceedance of recommended component service lives, inadequate mooring master and support craft resources, and procedural deviations during connection and disconnection in marginal weather. The pattern conforms to broader offshore experience in which hardware failure rates are strongly modulated by the quality of the surrounding integrity management system. Reviews of occupational safety management in oil and gas maintenance projects show that weaknesses in permit systems, contractor oversight, and competence assurance translate directly into equipment damage and unplanned outages (Obogo *et al*., 2020c; Arumosoye and Obriki, 2020), while conceptual work on human error causation in high risk industrial activities explains how latent organisational conditions combine with active errors during operations such as hose connection and tanker mooring (Obriki and Arumosoye, 2020). The systematic use of near miss and hazard observation data has been identified as an underexploited source of leading indicators in comparable industrial settings (Arumosoye and Obriki, 2019; Obogo *et al*., 2021a), and transferable organisational instruments include structured hazard identification and risk control reviews (Obogo *et al*., 2019c), leadership driven safety culture transformation and safety risk governance models for multi contractor operations (Obogo *et al*., 2019a; Obogo *et al*., 2019b), management safety walkthrough frameworks (Obriki and Arumosoye, 2019), and contractor safety compliance systems (Obogo *et al*., 2021c). Studies of Nigerian terminal operations specifically identify maintenance culture, spares availability, and contractor management as significant determinants of downtime.

Two organisational patterns deserve emphasis because they recur across otherwise different incident narratives. The first is normalisation of degraded states: a leak detection indicator known to be unreliable, a navigation light long extinguished, a hawser past its nominal retirement age, each individually tolerated until an initiating event finds the degraded barrier absent. The second is interface fragmentation: terminal operations, marine services, inspection contractors, and procurement frequently sit in different organisations, and failures cluster at the seams, for example when a hose tested by one contractor is repositioned by another without record transfer. A third pattern, less discussed but visible in the regional narratives, is experience thinning: the specialist knowledge that keeps an SPM terminal reliable, mooring mastery, hose handling craft, and familiarity with the individual quirks of an old buoy, resides in a small number of people, and contractor turnover, retirement, and security driven crew changes drain it faster than formal systems capture it. Terminal operations are also conducted by multinational teams, with tanker crews, mooring masters, contractors, and shore staff frequently drawn from different countries and first languages, so that the communication research on identity, diversity, and cross-cultural interaction bears directly on the reliability of instructions exchanged during mooring, transfer, and emergency evolutions (Lilian *et al*., 2020). Structured handover, retained site records, and deliberate overlap between outgoing and incoming personnel are the mundane countermeasures, and their absence is repeatedly identifiable in the run up to clustered failures at individual terminals. Both patterns are organisational rather than technical, and both respond to the governance instruments reviewed in Section 5 rather than to hardware investment.

3.7. Consequence profile of SPM failures

The consequences of the failure modes catalogued above fall into four partially overlapping categories: environmental release, safety exposure, availability loss, and asset damage. Environmental consequence is dominated by hose events, since hoses carry full flow at or near the surface and their failure releases cargo directly to the sea, frequently close to shorelines, fishing grounds, and estuarine communities. Regional spill records attribute the majority of terminal associated releases to hose rupture, leaking flanges, and connection and disconnection operations, with volumes ranging from operational sheens to multi thousand-barrel events, and the reputational and compensation consequences of shoreline impact in the Niger Delta context have repeatedly exceeded the direct cost of the failed component by orders of magnitude.

Availability consequence has a different structure. Hose failures, although frequent, are repairable within days where certified spares are stocked in country, whereas the rarer mechanical and structural failures, a seized main bearing, a parted mooring leg discovered late, or PLEM valve failure, remove the terminal from service for weeks to months because they require mobilisation of specialist vessels, imported components, or dry docking. Expected downtime is therefore driven by low frequency high duration events, while spill risk is driven by higher frequency hose events, and an integrity programme optimised against only one of these measures will misallocate effort. Safety exposure concentrates in the intervention activities that failures trigger, including emergency hose change out in marginal weather, diving on degraded moorings, and hot work on hydrocarbon wetted structures, so that reliability improvement is also directly a safety improvement.

Finally, consequence severity in the region is modulated by response capability. Containment and recovery resources, tug availability, and salvage support vary widely between terminals, and the same initiating failure produces materially different outcomes depending on detection speed and first response. This coupling between technical reliability and response readiness justifies treating emergency preparedness as part of the reliability system itself, and it explains why the integrity management framework of Section 5 includes operational and organisational measures alongside hardware inspection.

4. Reliability and Risk Assessment Methods Applied to SPM Systems

4.1. Qualitative and semi-quantitative methods

Failure Mode, Effects and Criticality Analysis (FMECA) is the most widely reported structured method for SPM terminals, used to rank subsystem failure modes by severity, occurrence, and detectability, and to direct inspection and spares strategy. Published applications to CALM systems consistently rank hose rupture, hawser failure, and mooring leg failure among the highest criticality items, in agreement with the incident record summarised in Section 3. Hazard and Operability (HAZOP) studies and bow-tie analyses are applied to transfer operations to structure preventive and mitigating barriers around the central loss of containment event. Adaptive safety management system implementation models developed for aerodromes in developing economy contexts demonstrate how structured hazard registers and assurance cycles can be sustained by infrastructure operators with constrained resources, an institutional problem shared by many regional terminals (Adeyelu, 2019).

Applied well, FMECA for an SPM terminal is more than a ranking exercise. The analysis forces explicit statement of each failure mode, its local and terminal level effect, the detection means currently in place, and the compensating provisions assumed, and it is precisely these detection and compensation assumptions that regional incident experience shows to be fragile. A criticality review that asks how a parted mooring leg would actually be detected at this terminal, with this monitoring fit, at this inspection interval, converts a generic worksheet into a site-specific improvement plan. Bow tie representations serve a complementary communication purpose, displaying for a loss of containment top event the preventive barriers, hose testing, surge control, mooring limits, and the mitigative barriers, leak detection, emergency shutdown, spill response, in a form that operations personnel and regulators can audit barrier by barrier. The underlying logic, that control effectiveness must be assessed against identified risk rather than assumed from procedure existence, is the same logic developed in risk based internal control and technology enabled risk assessment frameworks in other regulated sectors (Akomolafe and Agu, 2019a; Akomolafe and Agu, 2018).

HAZOP application to the transfer operation follows the process industry pattern with marine extensions. Deviation guidewords are applied node by node along the transfer path, from tanker manifold through floating string, buoy piping, swivel, submarine string, and PLEM to the shore line, and the marine nodes add deviations that a plant HAZOP would not see: excessive relative motion, hose twist during connection, tanker drift during a squall, and support craft interaction. Regional review experience shows the highest value findings cluster at operating mode transitions, start of transfer, rate changes, and emergency shutdown, where surge, communication, and simultaneous operations interact, and at the assumptions about tug and mooring master availability that quietly underpin many safeguards. Recording those dependency assumptions explicitly, and auditing them in operation, closes a gap between paper safeguards and field reality.

4.2. Quantitative reliability modelling

Quantitative studies apply Fault Tree Analysis to model terminal level events such as oil spill during transfer or loss of stationkeeping as logical combinations of component failures, using generic offshore failure rate databases, notably OREDA, supplemented by operator records where available. Reliability Block Diagrams and Markov models have been used to represent redundancy in dual hose strings, dual hawsers, and multi-leg mooring arrangements, and to quantify the availability benefit of condition monitoring that shortens the detection time of hidden failures such as a parted anchor leg. Bayesian methods have been proposed to update sparse regional failure data with expert judgement, an approach of particular relevance in West Africa where operator data are rarely published. In adjacent transport safety domains, artificial intelligence driven risk quantification models (Adeyelu, 2020) and predictive compliance monitoring frameworks built on operational complaint and incident data (Adeyelu, 2018) illustrate data driven risk estimation techniques that are transferable to terminal operations. Structural reliability methods, applying environmental load statistics to mooring line strength models in line with API RP 2SK and ISO 19901-7 formats, are used at the design stage to set safety factors for the squall dominated load regime of the Gulf of Guinea, and squall response analysis has become a standard element of regional mooring design following industry joint studies of West African metocean data.

A representative fault tree for the top event oil spill during transfer decomposes into hose containment failure, connection and disconnection release, swivel and piping leakage, and overload events consequent on mooring failure, each further resolved to basic events with assignable rates. Two structural features of such trees carry practical lessons. First, common cause terms dominate: a single squall simultaneously raises the probability of hawser overload, hose overbending, and human error under time pressure, so that treating these branches as independent understates risk materially, and squall frequency enters the model as an explicit environmental initiating condition. Second, detection and response appear as conditional events, so that the same physical failure contributes very different spill volumes depending on assumed detection time, which quantitatively justifies investment in monitoring relative to hardware.

For the mooring subsystem, structural reliability formulations compare load distributions, derived from metocean statistics through vessel and buoy response analysis, with resistance distributions for chain and hawser components degraded by corrosion, wear, and ageing. Because squall wind records are short, gusty, and directionally volatile, regional practice has moved toward time domain analysis in which measured squall records are applied to the moored system directly rather than through conventional sea state statistics. The practical output is a set of operating limits and safety factors that reflect the true regional load process; the reliability lesson is that transplanting temperate water design assumptions into this environment misestimates both the magnitude and the character of the governing loads.

State based models earn their place in this context principally through hidden failure representation. A Markov model of the mooring subsystem distinguishes states for all legs intact, one leg failed undetected, one leg failed detected, and system loss, with transition rates for failure, inspection driven detection, continuous monitoring detection, and repair; the model output, expected time in the undetected state and consequent system loss probability, responds sharply to the monitoring rate and hence prices monitoring investment directly. Bayesian structures serve a complementary role where data are sparse: prior distributions constructed from international databases and elicited expert judgement are updated with the modest regional evidence available, yielding usable posterior rates with honest uncertainty bounds instead of a false choice between unrepresentative foreign data and no analysis at all. Both techniques are computationally light and well within the reach of terminal engineering teams; their limited regional application reflects data and habit rather than difficulty.

4.3. Inspection and condition-based approaches

Risk Based Inspection (RBI) frameworks allocate inspection effort in proportion to the probability and consequence of failure of each component, and have been applied to hose strings, chains, and buoy structure. Nondestructive testing based integrity management and corrosion risk assessment strategies developed for process equipment provide directly transferable methods for buoy piping, swivel internals, and structural welds (Atta *et al*., 2020; Atta *et al*., 2021), and the broader industrial transition from reactive to predictive maintenance regimes, supported by condition data and structured deterioration models, is equally applicable to SPM mechanical systems (Sunday *et al*., 2020; Obriki and Arumosoye, 2018). For hoses, the OCIMF testing regime provides a natural condition assessment backbone, and several studies propose residual life models that combine test results with service age and cargo severity. For mooring legs, industry experience of hidden failures has motivated continuous buoy position monitoring, sonar and ROV based chain measurement, and inclination monitoring of the buoy as practical condition indicators. Emerging work reviewed up to 2021 explores digital monitoring of hose curvature and internal pressure, machine learning classification of leak detection signals, and digital twin representations of CALM systems, and interpretable machine learning methods demonstrated for early failure prediction in distributed energy assets indicate the direction such monitoring analytics are likely to take (Komi and Adamolekun, 2021; Komi, 2021), while enterprise log analytics and automated incident response architectures point to the alarm handling infrastructure such monitoring will require (Mbonu *et al*., 2019); reported field deployments in West Africa nonetheless remain limited. Methodologically, the problem of scoring condition from heterogeneous indicators is shared with data driven risk evaluation practice in other data sparse emerging market settings (Akomolafe and Agu, 2019b), and predictive analytics developed for anomaly detection in transaction monitoring illustrates the class of pattern recognition techniques applicable to leak detection and alarm triage signals (Atakpa, 2021). Evidence based platform design principles are equally relevant to the interfaces through which such analytics reach operators and trainees (Orise and Niniola, 2020). At the architectural level, risk based business intelligence structures show how analytic layers can be organised around risk exposure rather than around data availability (Mbonu *et al*., 2021a), dashboard frameworks address the executive visibility gap that separates terminal level knowledge from the shore management decisions it should inform (Sanni and Atima, 2021b), and forensic analytics practice demonstrates how event records are reconstructed into defensible causal accounts, which is precisely the requirement of post failure investigation (Mbonu *et al*., 2021c).

The economics of condition-based approaches at SPM terminals are favourable because the monitored assets are few, the failure consequences are large, and the marginal sensing cost is small against terminal throughput value. A practical monitoring hierarchy begins with buoy position and heading by GPS, which protects against hidden mooring failure; adds hawser tension measurement, which both enforces operating limits in real time and accumulates the load histories needed for rational retirement decisions; and extends to hose annulus pressure indication for double carcass strings, bearing condition trending, and periodic sonar profiling of chain and hose geometry. Each layer shortens detection time for a class of otherwise hidden failures, and availability models translate that shortened detection time directly into reduced expected downtime and spill volume, providing the investment justification in terms terminal owners recognise.

Looking slightly ahead of current regional practice, the integration layer above individual sensors is where the next reliability increment lies. A terminal level digital representation that holds the as installed configuration, unit level component histories, live monitoring feeds, and the load and degradation models of this section in one environment would allow each measurement to update remaining life estimates continuously, would make the hidden failure question, what is the probability that a leg is parted now, answerable numerically at any time, and would give shore management the same situational picture as the terminal. The constituent technologies, telemetry, cloud data platforms, and the modelling methods already reviewed, are commercially mature, and the analytics and governance practices demonstrated in adjacent industries indicate feasible implementation patterns; the binding constraints in the regional context are connectivity at remote terminals, cyber security of the resulting operational technology surface, and the organisational commitment to act on what the system reveals. Because such a platform becomes safety relevant once operators rely on it, its own engineering requires the assurance disciplines developed for regulated software environments: extraction and integration design that preserves data lineage from sensor to model (Badmus *et al*., 2019a), platform governance frameworks for regulated settings (Badmus *et al*., 2019b), controlled delivery pipelines and deployment tooling that prevent uncontrolled change to a live monitoring system (Badmus *et al*., 2018; Badmus *et al*., 2020), automated testing and regression control to confirm that model updates do not silently degrade alarm behaviour (Mbonu *et al*., 2021b), directory and access management for the resulting enterprise and field network (Ladapo *et al*., 2019; Ladapo *et al*., 2018), and explicit legal and ethical risk modelling for the operational data such systems accumulate (Mbonu *et al*., 2018).

4.4. Standards based design and verification

The reliability of an SPM terminal is fixed to a substantial degree at the design and procurement stage, and the governing documents therefore belong in a review of reliability methods. API RP 2SK and ISO 19901-7 define the analysis conditions, load cases, and factors of safety for the stationkeeping system, distinguishing intact and damaged conditions and requiring that the mooring survive defined environmental return periods with one leg failed. Classification society rules for single point moorings add structural, mechanical, and marine systems requirements for the buoy itself, together with survey regimes that, where a buoy is maintained in class, impose an external discipline of periodic renewal surveys. On the transfer path, GMPHOM 2009 governs hose design qualification, prototype testing, and production testing, and OCIMF hawser guidance defines rope specification, test loads, and accessories. The pattern of designing to a controlled specification within a highly regulated envelope, and of embedding safety, throughput, and sustainability objectives in that specification, is common to other regulated facility classes and has been formalised in regulatory compliant design systems, spatial and safety planning strategies, and materials and energy selection frameworks whose structure is instructive here (Ogbete *et al*., 2019; Ogbete *et al*., 2018; Ogbete *et al*., 2020).

Two verification themes connect these documents to observed regional reliability. The first is the integrity of the qualification chain: hoses and hawsers are safety critical consumables, and their reliability depends on purchasing genuinely qualified product, preserving traceability from prototype qualification through production test certificates to the installed unit, and storing components correctly before use. Regional procurement pressures, long supply chains, and the existence of unqualified imitations make this chain a genuine vulnerability, which is why procurement governance appears among the integrity measures of Section 5. The second theme is management of change: buoys designed against the tanker fleet and metocean understanding of the 1970s now serve different vessels under updated environmental statistics, and formal reassessment against current standards, rather than continued reliance on original approval, is the appropriate response for life extended assets. It should also be recognised that standards encode failure experience with a lag. The strengthened requirements on hose end fittings, double carcass adoption, out of plane bending provisions for chain connections, and squall specific analysis practice each followed clusters of service failures, several of which occurred at African terminals. Systematic regional feedback into the standards process, through incident reporting to OCIMF and participation in joint industry projects, is therefore itself a reliability mechanism, and the weakness of published regional data noted throughout this review correspondingly slows the improvement loop.

For terminals outside class, an equivalent verification discipline can be assembled from the same elements: an owner inspection scheme mapped explicitly onto the survey scope a classification society would apply, independent third party witnessing of critical activities such as bearing installation, hose testing, and mooring measurement campaigns, and periodic gap assessment against the current editions of the governing standards. The assessment output, a register of deviations between the as maintained terminal and present-day requirements, then becomes the backbone of the life extension case, distinguishing deviations that are acceptable with compensating measures, typically enhanced monitoring or restricted operating envelopes, from those that require physical rectification. Several regional life extension programmes have followed exactly this structure, and their documentation, where visible, provides some of the most detailed public evidence on the actual condition of aged regional assets.

5. Integrity Management and Mitigation Practice

The reviewed experience supports a set of integrity management practices whose adoption correlates with improved reliability at regional terminals:

- Hose management to OCIMF GMPHOM 2009, with documented periodic testing, defined retirement criteria based on age and condition, use of double carcass hoses with functioning leak detection at critical positions, and maintenance of certified spare hose stock in country to shorten change-out times, consistent with inventory availability and strategic procurement models developed for energy facility uptime (Okonkwo *et al*., 2018a; Okonkwo *et al*., 2018b).
- Hawser management including defined service life limits, periodic residual strength verification, correct chafe protection, dual hawser arrangements with verified load sharing, and squall response procedures covering tug standby, transfer suspension criteria, and emergency release.
- Mooring leg integrity programmes combining periodic diver or ROV inspection with continuous GPS watch circle monitoring, cathodic protection surveys and anode renewal, and quantitative wear and corrosion allowances tracked against retirement limits.
- Planned buoy refurbishment cycles addressing main bearing, swivel seals, structural steel, coatings, and valves, supported by grease sampling and breakout torque trending between dockings, with heavy lifting and installation phases governed by structured lifting risk management models (Obogo *et al*., 2020b).
- Procurement and supply chain measures including vendor governance and contract negotiation frameworks (Okonkwo *et al*., 2019), data driven and GIS enabled vendor evaluation and procurement processes (Ahiaeke Patrick *et al*., 2020; Ahiaeke Patrick *et al*., 2021), predictive demand forecasting for spares inventory (Aifuwa *et al*., 2020), supplier relationship management for resilience (Ike *et al*., 2021), end-to-end supply chain visibility and traceability (Nnabueze *et al*., 2021), digitalisation of supply chain processes with embedded IT risk controls (Mbonu *et al*., 2020a), procurement process automation for efficiency and transparency (Akinleye and Adeyoyin, 2021), analytics based cost and profitability review of procurement operations (Akin-Oluyomi *et al*., 2020), data driven operations performance management (Efobi *et al*., 2021), and machine learning demand and cash flow forecasting methods applicable to spares holding and working capital decisions (Tonoyan *et al*., 2021a; Tonoyan *et al*., 2021b; Dada *et al*., 2021b).
- Operational controls including mooring master oversight, weather and swell operating envelopes, surge pressure management during valve operations, and exclusion zone enforcement supported by security arrangements addressing theft and vandalism.
- Organisational measures including competency management for terminal and marine crews, incident reporting and learning systems consistent with organisational learning maturity models for safety performance (Arumosoye and Obriki, 2021), structured incident prevention practice in maintenance environments (Obogo *et al*., 2021b), institutionalised life-preserving safety practices (Obriki and Arumosoye, 2021), internal QHSE audit systems (Obogo *et al*., 2020a), continuous improvement methods adapted for resource constrained organisations (Ambali *et al*., 2021), integrated governance and compliance approaches to organisational resilience (Akomolafe and Agu, 2019c), and the control disciplines of budget compliance, statutory reporting, and reconciliation and workflow control that determine whether integrity budgets are executed as approved (Dogbatsey and Ebhojie, 2018; Dogbatsey *et al*., 2019), alongside audit against OCIMF and regulatory requirements.

Where these practices are implemented consistently, reported spill frequency and unplanned downtime decline substantially, and several regional operators have publicised long spill free operating periods following hose management reforms. Conversely, the most severe reported regional incidents are associated with life expired components, lapsed testing, or delayed response to early warning indications.

Table 2 consolidates these practices into an integrity task matrix by subsystem, indicating the principal tasks, the techniques in common use, and the typical basis on which intervals are set. The matrix is deliberately technique neutral: the reliability benefit lies less in any single method than in the completeness of coverage, the discipline of interval compliance, and the closure of findings into corrective action.

Table 2: Integrity management task matrix for SPM subsystems.

Subsystem	Principal integrity tasks	Typical techniques	Indicative basis
Floating hoses	Periodic testing, visual survey, position rotation, retirement	Hydrostatic and vacuum tests, electrical continuity, elongation measurement, leak detection checks	GMPHOM 2009 intervals; condition and age-based retirement
Submarine hoses	Geometry survey, testing at change-out, marine growth control	ROV or diver visual survey, catenary profile measurement, pressure testing	Change-out on age and condition; survey after mooring events
Hawsers	Service life control, hardware inspection, residual strength verification	Visual and tactile inspection, destructive testing of retired samples, load monitoring where fitted	Defined service hours or loadings; post squall inspection
Anchor legs	Dimension and wear measurement, cathodic protection survey, position verification	Diver or ROV gauging, CP potential survey, sonar profiling, GPS watch circle monitoring	Class or operator intervals; retirement on diameter loss criteria
Bearing and swivel	Lubrication, clearance and torque trending, seal renewal	Grease sampling, rocking clearance measurement, breakout torque tests, leak observation	Condition based; overhaul at planned refurbishment
Buoy structure	Thickness gauging, coating and anode renewal, closure checks	Ultrasonic gauging on fixed grid, visual survey, compartment soundings	Class survey cycle or equivalent owner scheme
PLEM and pipeline	External survey, valve exercising, span and scour monitoring	ROV visual and CP survey, partial valve stroking, geometry measurement	Periodic subsea campaigns; event driven surveys
Ancillaries	Function testing, power system checks, security verification	Navigation aid checks, battery and solar condition tests, telemetry verification	Frequent routine visits; immediate defect rectification

Beyond the task matrix, three implementation principles distinguish effective regional programmes. First, integrity data must be owned at unit level: every hose section, hawser, chain segment, and major mechanical component carries an identity against which history, test results, and position are recorded, so that decisions are made about specific ageing units rather than about generic populations. Second, intervals must survive disruption: security incidents, budget cycles, and vessel availability will interrupt any schedule, and programmes that define recovery rules, compensating measures, and escalation when intervals are exceeded degrade gracefully instead of silently. Third, findings must close: the review of regional audit material suggests that identified defects awaiting action, rather than unknown conditions, precede a substantial share of failures, which makes corrective action tracking a direct reliability control.

Emergency preparedness completes the integrity framework, consistent with the consequence analysis of Section 3.7. Effective regional practice ties the spill contingency plan to the specific failure modes of the terminal, prepositioning containment boom and recovery capability sized for a full-bore hose release, drilling the emergency hose disconnection and change out sequence so that it is executable in the sea states in which it will actually be needed, and maintaining agreements for tug, diving, and salvage support with mobilisation times that are tested rather than assumed. Exercises that rehearse the composite scenario, squall, hawser failure, hose damage, and spill in sequence, expose the coordination weaknesses that single hazard drills miss. Because the same launches, cranes, and personnel serve both routine maintenance and emergency response, investment in this capability also improves ordinary integrity work, a favourable coupling that budgeting processes should recognise.

6. Synthesis and Discussion

Bringing the strands of this review together, the West African SPM failure record resolves into a consistent structure. The transfer path, hoses, swivel, and their connections, generates the majority of loss of containment events and therefore dominates environmental risk; the stationkeeping path, hawsers and anchor legs, generates the events with the greatest escalation potential, since a breakout or undetected leg failure endangers every other subsystem simultaneously; and the mechanical and structural core of the buoy, bearing, hull, and PLEM, generates the long duration outages that dominate availability loss. This tripartite structure is not unique to the region, but the regional environment sharpens each part: swell fatigue accelerates the transfer path, squalls stress the stationkeeping path, and warm water corrosion, extended asset lives, and interrupted maintenance erode the mechanical core.

Comparing regional experience with the wider international record supports a second conclusion: the physics of failure is global, but the frequency and consequence of failure are local and largely organisational. The mechanisms catalogued in Section 3 appear in hose, mooring, and bearing failures worldwide, and the standards of Section 4.4 respond to them generically. What differentiates outcomes between terminals, within the region as much as between regions, is the completeness and persistence of the integrity system: whether tests happen on time, whether records follow components, whether monitoring exists for hidden failures, whether spares are on hand, and whether findings close. The best documented regional turnarounds, in which terminals moved from recurrent hose spills to extended spill free operation, were achieved without new technology, through disciplined application of existing guidance, which is simultaneously encouraging about feasibility and sobering about the true constraint.

A third theme concerns the interaction of security and reliability, which conventional reliability frameworks treat as an exogenous nuisance but which the regional record shows to be endogenous to system performance. Third party interference removes barriers directly, by disabling navigation aids and damaging pipelines, and indirectly, by suppressing the inspection and maintenance presence on which every other barrier depends. Periods of elevated security threat are therefore also periods of accelerated integrity debt, and the debt is repaid later as clustered failures. Treating surveillance, community engagement, and security response as components of the reliability system, plannable and auditable like inspection tasks, follows logically, and where that response is increasingly digital the identity centric and privacy centric security engineering models proposed for enterprise and cloud systems define the governance envelope required (Ogbole *et al*., 2021; Okoruwa *et al*., 2020), and the corridor monitoring and encroachment management frameworks cited in Sections 3.5 and 7 provide implementable models.

Fourth, the review highlights a measurement asymmetry that distorts decision making. Hose condition is measurable and hose failures are visible, so hoses attract attention and budget; mooring legs and bearings are hidden, their degradation is measured rarely, and their failures arrive as surprises. Rational allocation requires correcting for observability: the expected cost of the hidden subsystems, once realistic detection delays are included in the availability models of Section 4, is comparable to or greater than that of the visible ones, and the marginal value of monitoring investment is correspondingly highest exactly where current attention is lowest. The practical expression of this correction is the monitoring hierarchy of Section 4.3, led by continuous buoy position surveillance.

Finally, the age question deserves a direct statement. The regional fleet contains buoys that have delivered five decades of service, which demonstrates that the CALM concept, maintained, is remarkably durable; it also contains life expired components operating on inherited approvals, which the incident record shows to be the single most repeated precondition of severe events. Age itself is not the hazard; unmanaged age is. Structured life extension, combining reassessment against current standards, targeted renewal of the age sensitive components identified in Section 3, and enhanced monitoring in place of unavailable design margins, converts an ageing liability into a managed asset, and the alternative of continued informal extension converts it into an accumulating risk whose realisation date is unknown but whose realisation is not in doubt.

A comparative observation on FPSO export operations sharpens several of these points. Deepwater FPSO terminals in Angola and Nigeria operate the same hawsers and hose technologies as coastal CALM terminals, frequently in similar metocean exposure, yet generally report better component reliability. The differences are instructive and organisational: FPSO operations are typically younger assets under single operator control, with permanently attended facilities, integrated marine teams, continuous monitoring as standard fit, and capital structures that fund scheduled renewal. None of these advantages is intrinsic to deep water; each is a management arrangement that a coastal terminal can emulate in proportionate form. The comparison thus functions as an internal regional benchmark demonstrating that the environmental explanation for poor reliability, taken alone, is insufficient.

The recurring appeal in this review to regional data pooling deserves a concrete institutional sketch. A workable arrangement would collect anonymised component level records, hose test results and retirement cause, hawser service lives, chain gauging campaigns, bearing condition trends, and downtime events, through an independent custodian, with participation incentivised by access to the pooled analysis and protected by anonymisation rules of the kind long operated by international reliability data programmes. The population of regional terminals is small enough that even a few years of pooled records would transform the statistical basis for the models of Section 4, and large enough that no single operator can build that basis alone. Governance and architecture frameworks developed for national scale data interoperability and data quality provide a tested template for the custodianship, definitional consistency, and analytic layering such a pool would require (Ilodigwe and Adesemoye, 2021). Industry associations active in the region, classification societies, and the reorganised national regulators are each plausible convener, and the principal obstacle, commercial sensitivity, has been solved elsewhere by exactly the anonymisation architecture described.

Lastly, the findings travel. The combination identified here, a fatigue intensive environment, ageing single point assets, constrained maintenance ecosystems, and security pressure on inspection presence, characterises offshore loading operations in several other producing regions, and the ordering of interventions derived from West African experience, hidden failure detection first, consumable discipline second, qualification chain protection third, organisational closure throughout, is stated in terms independent of geography. Conversely, the regional record would benefit from systematic comparison with published terminal experience elsewhere as such material emerges, and the framework of this review, subsystem failure catalogue, consequence structure, method inventory, and integrity task matrix, is offered as a template that makes such comparisons commensurable.

7. Research Gaps and Future Directions

Several gaps emerge from this review. First, there is a scarcity of published, statistically usable failure rate data specific to West African SPM terminals; most quantitative studies rely on generic North Sea biased databases whose transferability to warm water, swell dominated, security affected operations are uncertain. A regional anonymised failure data initiative would materially improve reliability modelling. Second, ageing management of terminals operating far beyond design life deserves dedicated study, including structural reassessment methods for aged buoy hulls and chains under contemporary metocean statistics. Third, the interaction between security related interference and technical reliability has received little formal treatment, despite its evident contribution to downtime and spill risk in parts of the region; integrated UAV, LiDAR, and GIS corridor management frameworks demonstrated for other infrastructure classes offer a ready basis for such work (Dagodzo and Ahiaeke Patrick, 2021b), building on UAV inspection frameworks matured in power infrastructure programmes (Dagodzo, 2018a; Dagodzo, 2018b) and GIS based utility asset management practice (Dagodzo and Ahiaeke Patrick, 2021a). Fourth, digital condition monitoring of hoses, hawsers, and mooring legs is technically mature but sparsely deployed regionally, and pilot studies quantifying its availability benefit under local conditions would support wider adoption, and the operational technology networks that such monitoring introduces will themselves require protection, for which zero trust architectures proposed for critical infrastructure provide a candidate framework (Ahmed *et al*., 2021; Adegbite *et al*., 2020), supported by security audit and enterprise risk assessment, intrusion detection, incident response and digital forensics capability, and disciplined log analytics and secure deployment governance for the monitoring platforms themselves (Dosunmu and Ogundele, 2019; Dosunmu and Ogundele, 2020; Dosunmu and Ogundele, 2021; Mbonu *et al*., 2020b). Finally, climate driven changes in swell and squall statistics may alter design and operating envelopes, and updated regional metocean criteria should feed revised reliability assessments. Beyond these five, two further directions merit statement. Reliability economics for the region remains undeveloped: the cost structures of downtime, spill response, and component logistics at West African terminals differ enough from generic assumptions that locally calibrated cost of unreliability models would change optimisation results, particularly the balance between spares holding and expedited supply; the analytic apparatus for this work exists in the financial analytics and executive decision modelling literature and needs adaptation rather than invention (Lawal and Oduleye, 2018a; Lawal and Oduleye, 2019b; Lawal and Oduleye, 2021b), and the measurement problem itself, quantifying the return on expenditure whose benefit appears as absent failures, parallels the return on investment measurement challenge treated analytically in other regulated service settings (Sanni *et al.*, 2020a). Related governance questions, including how cross-border compliance obligations and internal transfer arrangements shape the cost of imported spares and contracted services, are similarly treatable with existing frameworks (Lawal and Oduleye, 2018b; Lawal and Oduleye, 2019a). And the human dimension invites dedicated study: the competency pipeline for mooring masters, terminal engineers, and inspection divers in the region, the retention of experience across contractor transitions, and the design of procedures that remain workable under the time pressure of squall onset are all researchable determinants of the organisational reliability that this review has repeatedly identified as decisive. Methodologically, future regional studies would gain from three practices that the reviewed literature applies unevenly: reporting denominators alongside failure counts, so that terminal years, hose years, and transfer counts convert anecdote into rate; describing the integrity regime in force at the time of each reported failure, so that hardware and organisational contributions can be separated; and archiving the underlying data in accessible form, so that later syntheses can aggregate rather than merely juxtapose. The present review has been constrained at several points by the absence of exactly these practices in its sources, and their adoption would do more for the cumulative value of regional research than any increase in publication volume.

8. Conclusion

Single Point Mooring systems remain indispensable to West African petroleum logistics, and their reliability is governed by a well characterised set of failure modes in which marine hoses, mooring hawsers, anchor chains, main bearings and swivels, buoy structure, and PLEM equipment dominate. Regional conditions, notably persistent South Atlantic swell, squalls, warm corrosive waters, extended asset lives, and third-party interference, intensify these failure mechanisms and add distinctive availability threats. Five decades of operating experience, read alongside international guidance from OCIMF, API, ISO, and classification societies, show that the failure record is largely explicable and that disciplined integrity management measurably improves outcomes. The principal obstacles to further progress are informational and organisational rather than conceptual: regional failure data are not shared, monitoring technology is under deployed, and inspection and change-out discipline varies between terminals. Addressing these gaps through regional data pooling, condition monitoring adoption, and reliability models calibrated to Gulf of Guinea conditions constitutes the clearest path to reducing spill risk and downtime at West African SPM terminals. The synthesis offered here also carries a practical ordering for operators: secure continuous detection of hidden mooring failures first, since these carry the greatest escalation potential; enforce the hose testing and retirement discipline second, since hoses dominate spill frequency; protect the qualification and traceability chain of safety critical consumables third; and institutionalise the recording, interval recovery, and corrective action closure practices on which all of the preceding depend. None of these steps requires capability beyond what regional terminals already possess, and the documented successes within the region demonstrate that the reliability performance of West African SPM systems is limited neither by the concept nor by the environment, but by the consistency with which known integrity practice is applied.

References

1. Adegbite MP, Adebayo A, Ahmed MO. Securing operational technology networks in electric utilities: a systematic review of NERC CIP compliance and architectural threat mitigation. Int J Eng Mod Technol. 2020;6(3):103-146. doi:10.56201/ijemt.vol.6.no3.2020.pg103.146.
2. Adeyelu OO. A predictive compliance monitoring framework for detecting systemic safety risks through aviation consumer complaint data. Iconic Res Eng J. 2018;1(8):250-276. doi:10.64388/IREV1I8-1718478.
3. Adeyelu OO. An adaptive safety management system implementation model for aerodromes in developing economy contexts. Iconic Res Eng J. 2019;3(4):628-654. doi:10.64388/IREV3I4-1718479.
4. Adeyelu OO. An artificial intelligence-driven conceptual model for wildlife strike risk quantification and aircraft airworthiness impact assessment at high-traffic African airports. Iconic Res Eng J. 2020;4(1):339-368. doi:10.64388/IREV4I1-1718482.
5. Adeyelu OO. A framework for managing encroachments and unauthorized structures around airport boundaries: regulatory evidence, enforcement, and corrective action protocols for Nigerian civil aviation. Int J Multidiscip Res Growth Eval. 2021;2(6):954-972. doi:10.54660/.IJMRGE.2021.2.6.954-972.
6. Agbabiaka J, Okonkwo CS, Ogunwole O, Mayo W, Okeke OT. Supply chain risk management model for EPC and gas processing projects. Iconic Res Eng J. 2019;3(2):968-980. doi:10.64388/IREV3I2-1713124.
7. Ahiaeke Patrick MC, Okonkwo CS, Mayo W, Okeke OT. A GIS enabled framework for modern ERP procurement processes. Int J Multidiscip Res Growth Eval. 2020;1(5):499-508. doi:10.54660/IJMRGE.2020.1.5.499-508.
8. Ahiaeke Patrick MC, Okonkwo CS, Mayo W, Okeke OT. Model for data driven vendor evaluation and bid selection using geospatial intelligence. Shodhshauryam Int Sci Refereed Res J. 2021;4(4):426-443. doi:10.32628/SHISRRJ214461.
9. Ahmed MO, Adegbite MP, Adebayo A. Zero trust architecture for operational technology in North American critical infrastructure: a framework for implementation and resilience optimization. Int J Eng Mod Technol. 2021;7(1):66-113. doi:10.56201/ijemt.vol.7.no1.2021.pg66.113.
10. 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. Int J Multidiscip Res Growth Eval. 2020;1(3):171-181. doi:10.54660/.IJMRGE.2020.1.3.171-181.
11. 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 Res Eng J. 2021;5(5):562-583. doi:10.64388/IREV5I5-1716957.
12. Akin-Oluyomi OT, Atima ME, Akinleye OK, Akokodaripon DA. Using Tableau and Excel for comprehensive profitability analysis in retail procurement operations. Int J Multidiscip Res Growth Eval. 2020;1(5):385-393.
13. Akinleye OK, Adeyoyin O. Process automation framework for enhancing procurement efficiency and transparency. Shodhshauryam Int Sci Refereed Res J. 2021;4(4):356-387.
14. Akomolafe O, Agu MU. A conceptual model for enhancing internal audit quality through technology-enabled risk assessment frameworks. Iconic Res Eng J. 2018;1(9):458-475.
15. Akomolafe O, Agu MU. A conceptual framework for developing risk-based internal control models in the insurance and banking sectors. Iconic Res Eng J. 2019;2(8):335-354.
16. Akomolafe O, Agu MU. A review of data-driven risk evaluation models for emerging market financial institutions. Iconic Res Eng J. 2019;3(6):433-448.
17. Akomolafe O, Agu MU. Advances in financial resilience through integrated governance and compliance strategies. Iconic Res Eng J. 2019;2(10):607-620.
18. Amaechi CV, Wang F, Hou X, Ye J. Strength of submarine hoses in Chinese-lantern configuration from hydrodynamic loads on CALM buoy. Ocean Eng. 2019;171:429-442.
19. Amayo EB. Multi algorithm of loss objective function of a single phase induction motor. Int J Dev Res. 2017;7(5):12805-12810.
20. Amayo EB, Popoola TT. Multi algorithm of weight objective function of a single phase induction motor. Int J Trend Res Dev. 2017;4(2):184-188.
21. Amayo EB, Popoola TT. Scientific study of telecommunication deployment in achieving quality network. Int J Trend Res Dev. 2017;4(5):311-314.
22. Amayo EB, Ubeku E, Oshevire P. Multi algorithm of a single objective function of a single phase induction motor. J Multidiscip Eng Sci Technol. 2015;2(12):3400-3403.
23. American Bureau of Shipping. Rules for building and classing single point moorings. Houston (TX): American Bureau of Shipping; 2014.
24. American Petroleum Institute. API RP 2SK: design and analysis of stationkeeping systems for floating structures. 3rd ed. Washington (DC): American Petroleum Institute; 2005.
25. Aminu-Ibrahim AY, Ogbete JC, Ambali KB. Developing sustainable diagnostic laboratory infrastructure models for emerging and resource constrained health systems. Iconic Res Eng J. 2018;1(8):118-132. doi:10.64388/IREV1I8-1713586.
26. Aminu-Ibrahim AY, Ogbete JC, Ambali KB. Capital project delivery models for high risk healthcare infrastructure in developing national health systems. Iconic Res Eng J. 2019;2(10):626-649. doi:10.64388/IREV2I10-1713588.
27. Aminu-Ibrahim AY, Ogbete JC, Ambali KB. Infrastructure driven expansion of diagnostic access across underserved and rural healthcare regions. Int J Multidiscip Res Growth Eval. 2020;1(5):691-706. doi:10.54660/IJMRGE.2020.1.5.691-706.
28. Arumosoye OM, Obriki OD. Development of an integrated heat stress risk conceptual model for industrial operations in extreme environments. Iconic Res Eng J. 2018;1(12):141-160. doi:10.64388/IREV1I12-1714415.
29. Arumosoye OM, Obriki OD. Systematic review of near-miss and hazard observation data utilization in industrial safety management. Iconic Res Eng J. 2019;3(2):981-999. doi:10.64388/IREV3I2-1714417.
30. Arumosoye OM, Obriki OD. A governance-oriented conceptual model for contractor safety performance in multi-contract industrial projects. Int J Multidiscip Res Growth Eval. 2020;1(5):728-740. doi:10.54660/.IJMRGE.2020.1.5.728-740.
31. Arumosoye OM, Obriki OD. Organizational learning-based conceptual maturity model for continuous safety performance improvement. Int J Multidiscip Res Growth Eval. 2021;2(1):970-980. doi:10.54660/.IJMRGE.2021.2.1.970-980.
32. Atakpa MI. A review of predictive analytics models for anti-money laundering detection in commercial banking systems. Int J Sci Res Comput Sci Eng Inf Technol. 2021;7(2):778-804. doi:10.32628/CSEIT2064813.
33. 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. Int J Eng Mod Technol. 2018;4(1):64-97. doi:10.56201/ijemt.vol.4.no1.2018.pg64.97.
34. 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. Int J Eng Mod Technol. 2020;6(2):19-46. doi:10.56201/ijemt.vol.6.no2.2020.pg19.46.
35. Atta S, Tofah P, Adenuga OM. Advances in non-destructive testing methods for weld integrity evaluation in high-capacity power infrastructure. Int J Eng Mod Technol. 2021;7(1):20-47. doi:10.56201/ijemt.vol.7.no1.2021.pg20.47.
36. Badmus O, Dosunmu AA, Ozowara DE. A systematic review of CI/CD pipeline strategies in Salesforce DevOps: tools, practices, and deployment outcomes. Iconic Res Eng J. 2018;2(6).
37. Badmus O, Dosunmu AA, Ozowara DE. A conceptual model for ETL design and data integration in Salesforce-centric enterprise architectures. Iconic Res Eng J. 2019;3(5).
38. Badmus O, Dosunmu AA, Ozowara DE. A governance framework for Salesforce platform management in regulated healthcare environments. Iconic Res Eng J. 2019;3(6).
39. Badmus O, Dosunmu AA, Ozowara DE, Anunagba CO. A comparative framework for Salesforce DevOps tooling: evaluating Copado, Flosum, and Salesforce DX across enterprise deployment contexts. Int J Multidiscip Res Growth Eval. 2020;1(5):1021-1031. doi:10.54660/.IJMRGE.2020.1.5.1021-1031.
40. Bureau Veritas. NR 494: rules for the classification of

offshore loading and offloading buoys. Paris: Bureau Veritas; 2015.
41. Chakrabarti SK, editor. Handbook of offshore engineering. Volumes I and II. Oxford: Elsevier; 2005.
42. Dada T, Isiekwu CP, Oluwo K. Advances in multinational cash flow consolidation and FX risk control using tiered treasury architecture. Iconic Res Eng J. 2021;4(11):601-620. doi:10.64388/IREV4I11-1714351.
43. Dada T, Isiekwu CP, Oluwo K. Designing CRM-based sales forecasting models for multichannel lending institutions. Iconic Res Eng J. 2021;5(3):451-466.
44. Dagodzo D. A conceptual framework for UAV integration into national power grid inspection programs. Iconic Res Eng J. 2018;2(5):391-412. doi:10.64388/IREV2I5-1716082.
45. Dagodzo D. A review of UAV applications in electrical transmission line inspection: methods, technologies, and challenges. Iconic Res Eng J. 2018;2(6):234-254. doi:10.64388/IREV2I6-1716083.
46. Dagodzo D, Ahiaeke Patrick MC. UAV-based pipeline and corridor monitoring: a review of current practices and emerging technologies. Iconic Res Eng J. 2020;3(10):574-597. doi:10.64388/IREV3I10-1716084.
47. Dagodzo D, Ahiaeke Patrick MC. A review of GIS applications in utility asset management and infrastructure planning. Iconic Res Eng J. 2021;5(3):468-492. doi:10.64388/IREV5I3-1716085.
48. Dagodzo D, Ahiaeke Patrick MC. An integrated framework for UAV, LiDAR, and GIS in infrastructure corridor management. Int J Sci Res Comput Sci Eng Inf Technol. 2021;7(5):497-524. doi:10.32628/CSEIT217566.
49. Dogbatsey EA, Ebhojie O. Budget compliance and statutory reporting in Sub-Saharan Africa: a systematic review of frameworks, gaps, and reform pathways. Zenodo. 2018. doi:10.5281/zenodo.20446859.
50. Dogbatsey EA, Ebhojie O, Oyeleye AO. Reconciliation control and financial workflow redesign in emerging market organizations: a conceptual framework. Zenodo. 2019. doi:10.5281/zenodo.20447103.
51. Dosunmu AA, Ogundele PO. Security audit and enterprise risk assessment frameworks for resilient information systems. Iconic Res Eng J. 2019;3(5):434-447. doi:10.64388/IREV3I5-1713225.
52. Dosunmu AA, Ogundele PO. Intrusion detection and prevention models for enhancing organizational cyber defense effectiveness. Iconic Res Eng J. 2020;4(6):310-324. doi:10.64388/IREV4I6-1713226.
53. Dosunmu AA, Ogundele PO. Incident response and digital forensics strategies for rapid cyber-attack containment. Gyanshauryam Int Sci Refereed Res J. 2021;4(4):239-258.
54. Efobi OZ, Akinleye OK, Fasawe O. Framework for data-driven operations management and performance improvement in educational institutions. Gyanshauryam Int Sci Refereed Res J. 2021;4(6):127-158.
55. Eyetsemitan RA, Ambali KB, Oyeleye AO, Fadayomi O. Multi-stakeholder governance alignment in joint venture operations: a conceptual framework for coordinating business processes in highly regulated environments. Iconic Res Eng J. 2020;4(4):418-441. doi:10.64388/IREV4I4-1716955.
56. 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. Int J Multidiscip Evol Res. 2021;2(2):52-62. doi:10.54660/IJMER.2021.2.2.52-62.
57. Ilodigwe L, Adesemoye AC. The data backbone of health system transformation: a governance and architecture framework for interoperability, data quality, and advanced analytics at national scale. Int J Health Pharm Res. 2021;6(2):52-76. doi:10.56201/ijhpr.vol.6.no2.2021.pg52.76.
58. Isiekwu CP, Oluwo K, Dada T. A conceptual model for CFO-led strategic finance in joint venture and cross-border partnerships. Iconic Res Eng J. 2021;4(7):383-400. doi:10.64388/IREV4I7-1714350.
59. International Organization for Standardization. ISO 19901-7: petroleum and natural gas industries. Specific requirements for offshore structures. Part 7: stationkeeping systems for floating offshore structures and mobile offshore units. Geneva: International Organization for Standardization; 2013.
60. Komi NM. Hybrid deep learning for wind power forecasting: from grid stability to market equity for small generators. Int J Multidiscip Res Growth Eval. 2021;2(6):989-1014. doi:10.54660/.IJMRGE.2021.2.6.989-1014.
61. Komi NM, Adamolekun A. Interpretable machine learning for early failure prediction in distributed renewable energy assets. Int J Multidiscip Res Growth Eval. 2021;2(6):1015-1038. doi:10.54660/.IJMRGE.2021.2.6.1015-1038.
62. Komi NM, Adeniji IO. Co-optimizing technical performance and community affordability in smart solar microgrids for underserved regions. Int J Eng Mod Technol. 2020;6(3):173-212. doi:10.56201/ijemt.vol.6.no3.2020.pg173.212.
63. Ladapo OO, Dosunmu AA, Jooda D, Abolaji TO. Lessons learned from offline assessment of security-critical systems: the case of Microsoft Active Directory. Iconic Res Eng J. 2018;2(6):277-299. doi:10.64388/IREV2I6-1717205.
64. Ladapo OO, Jooda D, Dosunmu AA, Abolaji TO. Implementation of Active Directory for efficient management of enterprise networks. Iconic Res Eng J. 2019;3(4):608-627. doi:10.64388/IREV3I4-1717206.
65. Lawal OA, Oduleye TE. A conceptual model for financial analytics driven enterprise value creation in technology firms. Iconic Res Eng J. 2018;2(2).
66. Lawal OA, Oduleye TE. A review and conceptual framework for tax governance and cross-border compliance analytics. Iconic Res Eng J. 2018;2(5).
67. Lawal OA, Oduleye TE. A conceptual risk assessment model for transfer pricing in multinational corporations. Iconic Res Eng J. 2019;2(12).
68. Lawal OA, Oduleye TE. Conceptualizing data driven executive decision systems for strategic financial planning. Iconic Res Eng J. 2019;3(3).
69. Lawal OA, Oduleye TE. A conceptual decision model for capital allocation using financial analytics. Gyanshauryam Int Sci Refereed Res J. 2021;4(2):269-295.
70. Lawal OA, Oduleye TE. Aligning financial planning analytics with corporate strategy: a conceptual integration model. Shodhshauryam Int Sci Refereed Res

J. 2021;4(3):319-346.
71. Lilian IN, Liadi KO, Yeboah TJ, Apelehin AA. Understanding cross-cultural communication: identity, diversity, and global interaction. Gyanshauryam Int Sci Refereed Res J. 2020;3(4):153-176. doi:10.32628/GISRRJ21352.
72. Mbonu IS, Aliliele C, Iwuanyanwu U, Oluoha OM. A conceptual framework for legal and ethical risk modeling in enterprise data protection governance systems. Iconic Res Eng J. 2018;2(2):207-226. doi:10.64388/IREV2I2-1714911.
73. 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 Res Eng J. 2020;3(11):566-593. doi:10.64388/IREV3I11-1714916.
74. Mbonu IS, Iwuanyanwu U, Aliliele C, Uzoka E. Advances in infrastructure as code governance for secure terraform based enterprise cloud deployments. Int J Multidiscip Res Growth Eval. 2020;1(5):811-828. doi:10.54660/.IJMRGE.2020.1.5.811-828.
75. Mbonu IS, Iwuanyanwu U, Uzoka E, Oluoha OM. Advances in enterprise log analytics and automated incident response architectures using Python and SIEM platforms. Iconic Res Eng J. 2019;3(2):1000-1019. doi:10.64388/IREV3I2-1714915.
76. Mbonu IS, Aliliele C, Iwuanyanwu U, Uzoka E. A conceptual framework for risk-based business intelligence architecture in financial technology platforms. Int J Multidiscip Res Growth Eval. 2021;2(6):731-746. doi:10.54660/.IJMRGE.2021.2.6.731-746.
77. Mbonu IS, Aliliele C, Iwuanyanwu U, Uzoka E. Advances in artificial intelligence techniques for secure software testing and automated regression control mechanisms. Int J Sci Res Comput Sci Eng Inf Technol. 2021;7(5):468-496. doi:10.32628/CSEIT217565.
78. Mbonu IS, Iwuanyanwu U, Aliliele C, Uzoka E. A review of VoIP forensic analytics models for financial fraud detection and regulatory compliance monitoring. Int J Multidiscip Res Growth Eval. 2021;2(6):711-730. doi:10.54660/.IJMRGE.2021.2.6.711-730.
79. 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. Int J Multidiscip Futur Dev. 2021;2(2):50-60. doi:10.54660/IJMFD.2021.2.2.50-60.
80. Obogo SF, Ozobu CO, Uduokhai DO. Advances in leadership driven safety culture transformation in large construction workforces. Iconic Res Eng J. 2019;3(5):507-523. doi:10.64388/IREV3I5-1715497.
81. Obogo SF, Ozobu CO, Uduokhai DO. Development of a construction safety risk governance model for multi contractor high rise projects. Iconic Res Eng J. 2019;2(9):502-522. doi:10.64388/IREV2I9-1715495.
82. Obogo SF, Uduokhai DO, Ozobu CO. Systematic review of hazard identification and risk control practices in urban construction projects. Iconic Res Eng J. 2019;2(12):666-681. doi:10.64388/IREV2I12-1715496.
83. Obogo SF, Arumosoye OM, Obriki OD. Advances in internal QHSE audit systems for industrial engineering operations. Iconic Res Eng J. 2020;4(4):399-417. doi:10.64388/IREV4I4-1715499.
84. Obogo SF, Arumosoye OM, Obriki OD. Conceptual risk management model for heavy lifting and crane installation engineering operations. Shodhshauryam Int Sci Refereed Res J. 2020;3(4):122-144. doi:10.32628/SHISRRJ214441.
85. Obogo SF, Arumosoye OM, Obriki OD. Critical review of occupational safety management systems in oil and gas maintenance projects. Shodhshauryam Int Sci Refereed Res J. 2020;3(4):145-166. doi:10.32628/SHISRRJ214442.
86. Obogo SF, Arumosoye OM, Obriki OD. Advances in proactive hazard recognition and near miss reporting systems. Int J Multidiscip Res Growth Eval. 2021;2(6):835-846. doi:10.54660/IJMRGE.2021.2.6.835-846.
87. Obogo SF, Obriki OD, Arumosoye OM. Conceptual model for incident prevention in industrial maintenance engineering environments. Int J Multidiscip Res Growth Eval. 2021;2(6):847-858. doi:10.54660/IJMRGE.2021.2.6.847-858.
88. Obogo SF, Uduokhai DO, Ozobu CO. Review of contractor safety compliance systems in infrastructure engineering projects. Int J Sci Res Civ Eng. 2021;5(4):76-100. doi:10.32628/IJSRCE215412.
89. Obriki OD, Arumosoye OM. Conceptual modeling of data-driven occupational safety risk control in large-scale energy infrastructure projects. Iconic Res Eng J. 2018;1(7):169-189. doi:10.64388/IREV1I7-1714414.
90. Obriki OD, Arumosoye OM. A conceptual framework linking management safety walkthrough frequency and coverage to safety culture outcomes in mega projects. Iconic Res Eng J. 2019;2(8):355-374. doi:10.64388/IREV2I8-1714416.
91. Obriki OD, Arumosoye OM. Conceptual framework for human error causation in high-risk construction and industrial activities. Int J Multidiscip Res Growth Eval. 2020;1(5):715-727. doi:10.54660/.IJMRGE.2020.1.5.715-727.
92. Obriki OD, Arumosoye OM. Conceptual model for institutionalizing life-preserving safety practices across project-based organizations. Int J Multidiscip Res Growth Eval. 2021;2(1):961-969. doi:10.54660/.IJMRGE.2021.2.1.961-969.
93. Ogbete JC, Aminu-Ibrahim AY, Ambali KB. Optimizing laboratory spatial planning strategies to improve diagnostic accuracy, safety, and clinical throughput. Iconic Res Eng J. 2018;2(1):87-113. doi:10.64388/IREV1I7-1713587.
94. Ogbete JC, Aminu-Ibrahim AY, Ambali KB. Regulatory compliant design systems for molecular and pathology laboratories in highly controlled environments. Iconic Res Eng J. 2019;3(4):607-631. doi:10.64388/IREV3I4-1713589.
95. Ogbete JC, Aminu-Ibrahim AY, Ambali KB. Sustainable materials selection and energy efficiency strategies for modern medical laboratory facilities. Int J Multidiscip Res Growth Eval. 2020;1(5):674-690. doi:10.54660/IJMRGE.2020.1.5.674-690.
96. Ogbete JC, Aminu-Ibrahim AY, Ambali KB. Risk managed construction strategies for complex and highly regulated healthcare facility developments. Int J Sci Res Comput Sci Eng Inf Technol. 2021;7(5):362-392. doi:10.32628/CSEIT217561.
97. Ogbole JI, Okoruwa PO, Fadayomi O, Abolaji TO,

Edivri J, Akeju B. Conceptual model for identity-centric zero trust architecture in enterprise security governance. Int J Sci Res Comput Sci Eng Inf Technol. 2021;7(5):393-415. doi:10.32628/IJSRCSEIT217562.
98. Ogunwole O, Okonkwo CS, Agbabiaka J, Mayo W, Okeke OT. Supply chain resilience framework for critical infrastructure and gas processing plants. Shodhshauryam Int Sci Refereed Res J. 2021;4(4):444-461. doi:10.32628/SHISRRJ214462.
99. Oil Companies International Marine Forum. Guide to manufacturing and purchasing hoses for offshore moorings (GMPHOM 2009). 5th ed. London: Witherby Seamanship; 2009.
100. Oil Companies International Marine Forum. Guidelines for the purchasing and testing of SPM hawsers. London: OCIMF; 2000.
101. Oil Companies International Marine Forum. Mooring equipment guidelines (MEG4). 4th ed. London: Witherby Seamanship; 2018.
102. Okojie JS, Abioye RF. Reconciling chemical safety with circular-economy targets: a decision framework for post-consumer recycled polymers in consumer-goods packaging. Int J Multidiscip Res Growth Eval. 2020;1(5):992-1006.
103. Okonkwo CS, Agbabiaka J, Ogunwole O, Mayo W, Okeke OT. Model for demurrage elimination and port logistics efficiency in emerging economies. Int J Multidiscip Res Growth Eval. 2020;1(5):552-562. doi:10.54660/IJMRGE.2020.1.5.552-562.
104. Okonkwo CS, Agbabiaka J, Ogunwole O, Mayo W, Okeke OT. Conceptual model for materials readiness and maintenance-driven supply chain performance. Int J Multidiscip Res Growth Eval. 2021;2(6):584-594. doi:10.54660/IJMRGE.2021.2.6.584-594.
105. Okonkwo CS, Ogunwole O, Okeke OT. Framework for strategic procurement optimization in oil and gas operations. Iconic Res Eng J. 2018;1(7):153-168. doi:10.64388/IREV1I7-1713119.
106. Okonkwo CS, Ogunwole O, Okeke OT. Model for inventory availability and plant uptime improvement in energy facilities. Iconic Res Eng J. 2018;2(4):160-172. doi:10.64388/IREV2I4-1713120.
107. Okonkwo CS, Ogunwole O, Okeke OT, Mayo W. Conceptual framework for cost reduction through contract negotiation and vendor governance. Iconic Res Eng J. 2019;2(9):468-482. doi:10.64388/IREV2I9-1713121.
108. Okonkwo CS, Ogunwole O, Mayo W, Okeke OT. Framework for regulatory-compliant procurement in high-risk energy environments. Int J Multidiscip Res Growth Eval. 2021;2(6):595-605. doi:10.54660/IJMRGE.2021.2.6.595-605.
109. Okoruwa PO, Fadayomi O, Akeju B, Edivri J, Ogbole JI, Abolaji TO. Conceptual model for privacy-centric security engineering in digital and cloud computing systems. Int J Sci Res Comput Sci Eng Inf Technol. 2020;7(5):371-389.
110. OREDA. Offshore and onshore reliability data handbook. 6th ed. Trondheim: OREDA Participants/SINTEF; 2015.
111. Orise C, Niniola S. Data-informed digital learning platforms: a conceptual framework for evidence-based educational technology in healthcare and STEM environments. Int J Multidiscip Res Growth Eval. 2020;1(5):563-575.
112. Oshevire P, Eyenubo OJ, Amayo B. Voltage control in the presence of distributed generation. ATBU J Sci Technol Educ. 2017;5(2):165-173.
113. Sanni JO, Ajiga D, Atima ME. Analytical models addressing measurement challenges of marketing return on investment in regulated services. Int J Multidiscip Res Growth Eval. 2020;1(5):636-648. doi:10.54660/IJMRGE.2020.1.5.636-648.
114. Sanni JO, Atima ME. Business intelligence dashboard frameworks resolving executive visibility gaps in strategic marketing governance. Int J Multidiscip Res Growth Eval. 2021;2(6):633-646. doi:10.54660/IJMRGE.2021.2.6.633-646.
115. Sunday EA, Omoegun GO. Integrating solar power solutions in small-scale manufacturing industries in Nigeria. Int J Sci Res Sci Eng Technol. 2018;4(8):832-853.
116. Sunday EA, Omoegun GO. Optimizing electrical load distribution for hybrid solar installations in developing economies. Int J Sci Res Mech Mater Eng. 2019;3(6):27-47.
117. Sunday EA, Omoegun GO, Essien MA, Oluokun OA. Transitioning from reactive to predictive maintenance in mechanical systems. Int J Sci Res Comput Sci Eng Inf Technol. 2020;6(6):425-447.
118. Tonoyan A, Dada O, Ayivi-Donkor SS. Advances in demand forecasting: machine learning algorithms for revenue projection and financial planning accuracy. Gyanshauryam Int Sci Refereed Res J. 2021;4(1):282-317.
119. Tonoyan A, Dada O, Ayivi-Donkor SS. Predictive cash flow modeling in retail: a review of advanced forecasting and working capital optimization. Shodhshauryam Int Sci Refereed Res J. 2021;4(3):366-397.
120. Yeboah BK, Ike PN. Programmatic strategy for renewable energy integration: lessons from large-scale solar projects. Int J Multidiscip Res Growth Eval. 2020;1(3):306-315. doi:10.54660/.IJMRGE.2020.1.3.306-315.