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Grease Analysis as a Predictive Maintenance Concept for Offshore Crude Export Mechanical Assets

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Abstract

Offshore crude export systems depend on a small population of grease lubricated mechanical assets whose failure carries disproportionate commercial and environmental consequences. Single point mooring (SPM) buoy main bearings, floating production storage and offloading (FPSO) turret and swivel assemblies, marine loading arm slewing rings, export pump and driver bearings, hose reel and winch drives, and pedestal crane slew bearings are all grease lubricated, difficult to access, and in several cases impossible to replace without extended export shutdown. Conventional condition monitoring on these assets is constrained: Vibration signatures from slow rotating, intermittently loaded bearings are weak, and oil analysis does not apply because there is no circulating oil to sample. This paper develops the case, as it stood in 2023, for in-service grease analysis as the primary predictive maintenance technology for this asset class. It reviews the failure behavior of grease lubricated offshore export equipment, the maturation of grease sampling and testing standards (notably ASTM D7718 for sampling and ASTM D7918 for die extrusion testing of small in-service samples), the diagnostic parameters that correlate with incipient bearing and gear distress, and a practical implementation framework covering sampling design, laboratory selection, limit setting, competence, digital architecture, data governance, cybersecurity, spares strategy, assurance, and economics. Drawing on a wide body of adjacent research in condition monitoring, integrity management, remote inspection, energy autonomous sensing, industrial safety analytics, supply chain readiness, and asset lifecycle data governance, the paper argues that grease analysis converts the largest blind spot in offshore export asset condition monitoring into a measurable, trendable data stream at low cost and with minimal intrusion, and it identifies the organizational, digital, and technical prerequisites for a successful program.

Keywords: Grease Analysis, Predictive Maintenance, Condition Monitoring, Single Point Mooring, FPSO, Crude Oil Export, Slew Bearing, ASTM D7718, ASTM D7918, Reliability Centered Maintenance, Asset Integrity

1. Introduction

1.1 Commercial Context of Offshore Crude Export

Crude oil export is the final and most commercially exposed step in the offshore production chain. Whether crude leaves the field through a single point mooring buoy at the end of a subsea export line, across the bow of an FPSO through an offloading system, or over a fixed jetty through marine loading arms, the export path is a series arrangement of mechanical assets with little or no installed redundancy. When an export bearing, swivel, or loading arm fails, production is either curtailed into limited storage or shut in entirely. Deferment costs for a mid-sized terminal handling 200,000 to 400,000 barrels per day are measured in millions of dollars per day, before any consideration of contractual demurrage, reputational damage, or the environmental risk associated with a mooring or transfer system failure during a tanker operation.

The scale of that exposure is documented across the energy operations literature. Modeling of port logistics efficiency in emerging market export operations shows that demurrage and loading delays impose penalties large enough to justify dedicated elimination programs in their own right (Okonkwo, Agbabiaka, Ogunwole, Mayo, and Okeke, 2020). Risk management modeling for engineering, procurement, and construction and gas processing projects demonstrates that single points of mechanical failure propagate rapidly into downstream commercial commitments (Agbabiaka, Okonkwo, Ogunwole, Mayo, and Okeke, 2019), and supply chain resilience frameworks for critical infrastructure identify unmonitored, long lead, single point assets as the dominant driver of extended outage duration (Ogunwole, Okonkwo, Agbabiaka, Mayo, and Okeke, 2021). Procurement optimization studies in oil and gas operations reach the same conclusion from the commercial side, namely that the cost of an unplanned outage is dominated not by the repair itself but by the acquisition lead time of the item that failed (Okonkwo, Ogunwole, and Okeke, 2018a; Okonkwo, Ogunwole, Okeke, and Mayo, 2019). Predictive analytics work on demand forecasting in supply chain operations reinforces that anticipation, rather than reaction, is the lever that changes this economics (Aifuwa, Oshoba, Ogbuefi, Ike, Nnabueze, and Olatunde-Thorpe, 2020).

1.2 The Asset Population and the Monitoring Gap

The mechanical assets on this export path share a defining characteristic: Nearly all of their critical rotating and articulating elements are grease lubricated. SPM buoy main roller bearings, turntable and turret bearings, product swivel path bearings, loading arm slewing rings and swivel joints, mooring hawser and hose reel winch gearboxes and open gears, export pump motor rolling element bearings, and pedestal crane slew rings all rely on grease rather than circulating oil. Grease is chosen for good reasons. It stays in place in slow, oscillating, heavily loaded contacts, it seals against salt spray and washdown water, and it tolerates long intervals between attention. However, the same properties that make grease the correct lubricant make the assets it serves nearly invisible to the two condition monitoring technologies that dominate offshore predictive maintenance: Vibration analysis and circulating oil analysis.

Vibration analysis performs poorly on large diameter, slow rotating bearings, where rotational speeds are often below one revolution per minute, defect frequencies fall below practical measurement bandwidths, and signal energy from early stage damage is buried in structural and wave induced noise. Oil analysis simply does not apply, because there is no oil reservoir or circulating system to sample. The result, common across offshore export terminals through the early 2020s, is that the most consequential mechanical assets in the export chain were maintained on time based regreasing schedules and periodic visual or internal inspection, with failure development between inspections essentially unmonitored. Because inventory availability and materials readiness models both show plant uptime to be governed by whether the right long lead spare is held and released in time (Okonkwo, Ogunwole, and Okeke, 2018b; Okonkwo, Agbabiaka, Ogunwole, Mayo, and Okeke, 2021), an asset class that gives no advance warning of its own degradation is precisely the class that defeats those models.

1.3 The Concept in Brief

Grease analysis closes this gap. The concept is straightforward: Grease in service accumulates a chemical and physical record of the contact it lubricates. Wear metals from raceways, rolling elements, gear teeth, and cages embed in the thickener matrix. Water, salt, and process fluid contamination alter grease consistency and chemistry. Oxidation and additive depletion signal thermal distress and end of useful grease life. By extracting small, representative in-service samples and subjecting them to a structured laboratory test slate, an operator can trend the health of both the lubricant and the machine, detect incipient failure months before functional failure, and time interventions such as purge regreasing, seal replacement, or bearing change out to actual condition rather than to the calendar.

Although grease analysis as a laboratory discipline is decades old, three developments made 2023 a credible inflection point for adopting it as a formal predictive maintenance concept on offshore export assets. First, standardization matured: ASTM D7718 provided a recognized practice for obtaining representative in-service grease samples, and ASTM D7918 established a die extrusion method that yields wear, contamination, consistency, and oxidation data from samples as small as one gram. Second, commercial laboratories and field kits made routine grease analysis logistically practical for remote offshore locations. Third, the reliability community, informed by ISO 14224 failure data structures and industry experience with SPM main bearing and turret bearing failures, recognized that this asset class needed a monitoring technology of its own.

1.4 Objectives and Scope

The objectives of this paper are fivefold: To characterize the failure behavior and monitoring constraints of grease lubricated offshore crude export assets; to review the state of grease sampling and analysis technology and standards as of 2023; to define a diagnostic parameter set and alarm philosophy suitable for this asset class; to present an implementation framework covering organization, competence, digital architecture, security, spares, and assurance; and to establish the economic case. The scope covers export path mechanical assets at SPM and conventional buoy moored terminals, FPSO offloading systems, and fixed jetty loading facilities. Subsea equipment, cargo tanker equipment, and process plant machinery upstream of export pumps are outside the scope, although the methodology transfers readily.

1.5 Note on Framing and Sources

The concept is presented as it was formulated in 2023, when the enabling standards and laboratory logistics first aligned, and the supporting literature is drawn exclusively from work published up to and including that year. The evidence base is deliberately wide in domain rather than in date, because the reasoning that underpins the concept, namely that dispersed and hard to reach high consequence assets become manageable once a modest but genuinely diagnostic measurement is taken regularly and tied to a persistent asset record, had by 2023 been established independently in condition monitoring, integrity management, remote inspection, sensing, industrial safety analytics, supply chain readiness, and asset data governance.

1.6 Structure of the Paper

Section 2 reviews the literature and standards across eight strands. Section 3 describes the asset class, its failure modes, and monitoring limitations. Section 4 presents grease analysis technology. Section 5 develops the predictive maintenance concept. Section 6 addresses implementation across organization, safety, digital architecture, security, procurement, assurance, economics, and environmental performance. Section 7 discusses limitations and research needs, and Section 8 concludes.

2. Literature and Standards Review

2.1 Grease Lubrication and Degradation Mechanisms

Lubricating grease is a semi-solid dispersion of a thickener, most commonly a lithium or lithium complex soap and increasingly calcium sulfonate or polyurea in marine service, in a base oil with performance additives. Lugt (2013) provides the standard treatment of grease lubrication mechanics in rolling bearings, describing the churning and bleeding phases by which grease releases base oil into the contact, and establishing that grease life, rather than fatigue life, frequently governs bearing life in sealed and hard to access applications. Grease degrades through interacting mechanisms: Mechanical shear breaks down thickener structure and softens the grease; oxidation hardens and acidifies it; water ingress can either soften or harden grease depending on thickener chemistry while promoting corrosion and washout; and contamination with abrasive solids accelerates wear of the very surfaces the grease protects. Because grease does not circulate, degradation and contamination are localized, which is a diagnostic advantage: The grease adjacent to a damaged contact carries a concentrated signature of that damage. The wider lubricant characterization literature confirms that base oil composition, contamination history, and blend integrity are all measurable through structured laboratory analysis, as demonstrated in comparative studies of alternative and contaminated oil feedstocks and their effect on tribological and combustion behavior (Bello, Azeez, Tawose, Odesanya, Odumosu, and Oyelaran, 2023).

2.2 Development of In-Service Grease Analysis

Early grease analysis practice borrowed oil analysis methods, notably elemental spectroscopy by ASTM D5185 after solvent dilution or ashing, Fourier transform infrared (FTIR) spectroscopy following ASTM E2412 practice for oxidation and water, and quarter and half scale cone penetration by ASTM D1403 for consistency. The persistent obstacle was sample size and representativeness: Classical methods required tens of grams, while a purged bearing might yield only a smear. Two ASTM developments addressed this. ASTM D7718 standardized low intrusion sampling of in-service grease using syringe style thief samplers through grease fittings, vent ports, and drain plugs, and established practices for sampling from purge streams and from opened housings. ASTM D7918 standardized the die extrusion method, in which roughly one gram of grease is extruded as a thin ribbon on a substrate, permitting colorimetric and FTIR evaluation of oxidation, linear sweep voltammetry for remaining antioxidant, ferrous debris measurement, and an extruded flow measurement that correlates with consistency change. Complementary methods include ferrous density meters, analytical ferrography of solvent dispersed grease per ASTM D7684 guidance, particle counting, Karl Fischer water by ASTM D6304 with suitable extraction, and rheometry for structural breakdown. By 2023 several major laboratories offered packaged in-service grease analysis slates around these standards, and bearing manufacturers including SKF published grease test kits and interpretation guidance.

2.3 Condition Monitoring of Slow Rotating and Offshore Export Assets

Vibration analysis remains the reference technology for conventional speed rotating machinery, and instrumented implementations demonstrate reliable defect detection on machines operating in normal industrial speed ranges (Omoegun, Sunday, Essien, and Oluokun, 2023). Related work on thermodynamic efficiency and control strategies in mechanical plant shows how operating parameter trending complements defect detection where the machine offers accessible process signals (Sunday, Omoegun, Essien, and Oluokun, 2019), and sensor based fault detection studies confirm that permanently instrumented systems detect developing faults earlier than periodic inspection (Sunday and Omoegun, 2022). None of these approaches, however, resolves the slow speed case. The literature on slow speed bearing monitoring consistently reports the weakness of conventional vibration methods below roughly 10 rpm and the partial remedies offered by acoustic emission, stress wave, and ultrasonic techniques. Studies of wind turbine pitch and yaw bearings, which are close mechanical analogues of crane and loading arm slew rings, found grease sampling to be among the most reliable early indicators of raceway spalling and false brinelling, since debris generation precedes any detectable change in torque or vibration.

In the offshore export domain specifically, published experience is dominated by failure investigations rather than monitoring studies: OCIMF guidance for single point moorings, SPM main bearing failure case histories, and FPSO turret bearing integrity programs all identify the main bearing as a top ranked integrity threat with limited monitoring options. This body of experience, together with ISO 14224 failure mode taxonomies and OREDA reliability data showing bearing and lubrication related causes prominent among rotating equipment failures, frames the opportunity that this paper develops. The situation parallels the wider integrity management literature for oil and gas facilities, where non-destructive testing and corrosion risk assessment strategies were developed precisely because critical equipment could not be monitored through operating parameters alone (Atta, Tofah, Kankam, and Adenuga, 2020). That literature further establishes the methodological pattern this paper follows, namely that inspection technologies become reliable predictive tools only when supported by codified methods and quality assurance regimes, as shown in the development of weld integrity evaluation methods for high capacity infrastructure (Atta, Tofah, and Adenuga, 2021) and in the standardization of welding inspection and quality assurance practice on large power generation projects (Atta, Adjaklo, Asomani, and Adenuga, 2022).

2.4 Predictive Maintenance and Reliability Frameworks

The concept sits within established predictive maintenance theory and within the documented transition of industrial maintenance practice from reactive repair toward condition based and predictive strategies (Sunday, Omoegun, Essien, and Oluokun, 2020). The P-F interval model holds that a detectable potential failure condition P precedes functional failure F by an interval during which intervention is possible; a monitoring technology is useful when its detection point falls early on the P-F curve and its inspection interval is comfortably shorter than the P-F interval. Reliability centered maintenance, as codified in SAE JA1011, assigns monitoring tasks only where a failure mode is detectable, the consequence justifies the task, and the task interval is technically and economically feasible. Programmatic experience in energy asset deployment demonstrates the same requirement, namely that preventive and predictive tasks be built around measurable degradation indicators rather than calendar convenience, and that the monitoring plan be designed alongside the asset rather than retrofitted to it (Yeboah and Ike, 2020; Komi and Adeniji, 2020).

Adjacent work in service reliability engineering supplies the operational vocabulary for running such a program at scale. Predictive capacity planning models demonstrate how forecast demand is converted into resourcing decisions ahead of need rather than after it (Edivri and Oteri, 2022), which is the same logic by which a grease trend is converted into a procurement and intervention plan. The service management literature adds the practical requirement that condition findings be raised, tracked, and closed within a controlled workflow rather than by correspondence (Ladapo, Dosunmu, Jooda, and Abolaji, 2023b; Ladapo, Jooda, Dosunmu, and Abolaji, 2023a). ISO 17359 provides the general framework for condition monitoring program design, and ISO 18436 governs personnel competence.

2.5 Conceptual Foundations from Adjacent Asset Domains

Several domains have solved a structurally identical problem, namely how to monitor dispersed, hard to reach, high consequence assets, and their conclusions transfer directly to offshore export equipment. Work on distributed renewable energy assets shows that interpretable machine learning applied to sparse condition data can generate useful early failure predictions well before functional failure, provided the underlying measurements track a genuine degradation mechanism (Komi and Adamolekun, 2021). Tiered digital twin architectures developed for resource constrained sites demonstrate that predictive diagnostics need not depend on dense instrumentation, and that a modest, well chosen measurement set feeding a structured model delivers most of the diagnostic value (Komi and Adeniji, 2023). Systematic review of control architectures for distributed energy resources clarifies where decision authority should sit between local and central layers, a question that recurs when deciding whether a grease alarm is actioned offshore or onshore (Komi and Adamolekun, 2022), and edge intelligence research for resilient microgrid control makes the same case for local processing where connectivity is unreliable (Komi and Ganiu, 2023).

Degradation modeling in other asset classes is equally instructive. Studies of grid connected battery storage in hot and weak grid regions show how ambient conditions accelerate degradation in ways that generic lifetime models fail to capture, which is directly analogous to the effect of tropical offshore conditions on grease life (Komi and Ganiu, 2022). Hybrid deep learning work on wind power forecasting establishes the general point that prediction quality depends on the physical fidelity of the input variables rather than on model sophistication alone (Komi, 2021). Edge intelligence architectures for distributed measurement establish the data pipeline pattern that periodic grease results can eventually feed (Komi and Ganiu, 2023).

The offshore environmental engineering literature supplies the operating context. Lifecycle risk assessment frameworks for offshore produced water management model exactly the kind of remote, weather constrained, consequence heavy offshore operation in which any monitoring program must function (Falegan and Aniebonam, 2022). Treatment strategy reviews for constrained environments show that process selection is driven by what can realistically be operated and maintained on site rather than by laboratory optimum, which is exactly the logic that should govern the choice of a monitoring method for an offshore export terminal (Falegan and Aniebonam, 2023). Related decision frameworks reconciling material compliance obligations with lifecycle objectives demonstrate how such competing criteria are brought into a single operational decision rather than resolved informally (Okojie and Abioye, 2020).

2.6 Remote Inspection and Geospatially Referenced Asset Monitoring

Remote inspection research provides a second foundation, and its central lesson is that condition data becomes actionable only when it is tied to position and to a persistent asset record. Conceptual frameworks for integrating unmanned aerial vehicles into national grid inspection programs establish the institutional pattern by which a new inspection technology is absorbed into an existing maintenance regime (Dagodzo, 2018a), while reviews of transmission line inspection document the methods, technologies, and limitations that determine where such techniques can and cannot replace physical inspection (Dagodzo, 2018b). Reviews of pipeline and corridor monitoring record the shift from calendar based physical inspection to targeted, condition triggered inspection of linear infrastructure (Dagodzo and Ahiaeke Patrick, 2020), and integrated frameworks combining aerial survey, laser scanning, and geographic information systems show how heterogeneous condition evidence is fused against a single spatial reference (Dagodzo and Ahiaeke Patrick, 2021b).

The asset management side of the same literature is equally relevant. Reviews of geographic information system applications in utility asset management show how spatially referenced condition data becomes decision grade once it is bound to a persistent asset record (Dagodzo and Ahiaeke Patrick, 2021a), and frameworks for integrating drone operations into enterprise systems demonstrate that the integration problem, not the sensing problem, is usually the binding constraint (Dagodzo and Ahiaeke Patrick, 2023a). Detection method reviews for encroachment and change along corridors illustrate how repeated observation at fixed reference points supports change detection rather than snapshot assessment (Dagodzo and Ahiaeke Patrick, 2022), and machine learning classification work on corridor imagery shows how the interpretation burden of high volume condition data is eventually automated (Dagodzo, Ahiaeke Patrick, and Aliliele, 2022). The circumferential sampling scheme proposed later in this paper applies the same principle to a five meter bearing rather than a transmission corridor: Position matters, and position must be recorded.

2.7 Sensing, Instrumentation, and Energy Constrained Monitoring

A third foundation comes from low power sensing research, which defines the feasibility envelope for any future permanently installed alternative to periodic grease sampling. Systematic reviews of radio frequency energy harvesting establish what is achievable for energy autonomous sensing in locations without wired power (Asiedu and Quainoo, 2023a), and simulation work on reliability in large scale intermittently powered networks addresses directly what a maintenance free monitoring installation can and cannot guarantee (Asiedu and Quainoo, 2023b). Taken together, these establish that the binding constraints on unattended offshore instrumentation are power availability and reporting reliability rather than sensor sensitivity, which is why the concept developed in this paper treats permanently installed grease sensing as a research direction rather than as an available option.

Control architecture research completes the picture by addressing where the decision logic for such a sensor should sit. Systematic comparison of hierarchical, decentralized, and hybrid control architectures clarifies the trade-offs involved in placing interpretation locally rather than centrally (Komi and Adamolekun, 2022), a question that recurs directly when deciding whether a grease alarm on a buoy is actioned offshore or onshore.

2.8 Leading Indicators, Safety Analytics, and Continuous Monitoring

A fourth strand comes from industrial safety management, which has spent two decades solving the same epistemic problem that grease analysis addresses: How to manage rare, high severity outcomes using frequent, low severity observations. Systematic review of near miss and hazard observation data utilization establishes that the value of a low severity signal lies in the volume of observations it generates rather than in the significance of any single observation (Arumosoye and Obriki, 2019), and work on proactive hazard recognition and near miss reporting systems shows how such signals are converted into intervention (Obogo, Arumosoye, and Obriki, 2021). Conceptual modeling of data driven occupational risk control in large scale energy infrastructure projects sets out the general architecture by which observation streams become control mechanisms (Obriki and Arumosoye, 2018).

The subsequent literature makes the continuity argument explicitly. Frameworks for proactive hazard identification using digital safety data streams show that organizations reduce consequence exposure by converting rare events into routinely observable leading indicators (Obriki and Arumosoye, 2023), and work on continuous hazard monitoring systems makes the case for sustained observation over periodic audit (Obriki, Arumosoye, and Obogo, 2023). Studies linking the frequency and coverage of management observation to safety culture outcomes establish that the discipline of looking, not the sophistication of the instrument, drives the result (Obriki and Arumosoye, 2019), while analyses of why undesired conditions recur despite being known show what happens when observation is not converted into intervention (Obriki and Arumosoye, 2022). Reviews of behavioral programs demonstrate how sustained observation regimes are maintained across large workforces (Obriki, Obogo, and Arumosoye, 2023), and hazard identification and risk control reviews show how the observation set itself is broadened over time (Obogo, Uduokhai, and Ozobu, 2019). Grease analysis performs precisely this conversion for the export asset class.

3. Offshore Crude Export Mechanical Assets: Failure Behavior and Monitoring Constraints

3.1 The Export Asset Population

A representative crude export terminal, whether buoy based or jetty based, contains the following grease lubricated critical assets. The SPM or CALM buoy main bearing is a large diameter three race roller or wheel and rail bearing, typically 3 to 5 meters in diameter, that allows the buoy turntable to weathervane with the moored tanker; it operates at fractions of a revolution per minute under combined mooring, hose, and wave loads, and its replacement generally requires taking the buoy off station. Product swivel assemblies on the buoy or FPSO turret transfer crude across the rotating interface through stacked toroidal chambers supported on grease lubricated bearings with elastomeric seals. Marine loading arms at jetty terminals articulate on grease lubricated swivel joints and slew on large ring bearings, with counterweight sheaves and emergency release couplings adding further greased elements.

Export pumps and their drivers, where not oil lubricated, run on grease packed rolling element bearings, as do most motor operated valve actuators on the export header. The loss characteristics and thermal behavior of the driving electrical machines bear directly on bearing cavity temperature and therefore on grease life, and multi-objective analyses of induction machine losses and mass provide the framework within which those thermal and design trade-offs are made explicit (Amayo, 2017; Amayo and Popoola, 2017a; Amayo, Ubeku, and Oshevire, 2015). Variable speed drive topologies increasingly common on export pumps alter both thermal duty and shaft current exposure (Adenuga, 2023), and where terminals draw on distributed or hybrid generation, supply side voltage behavior adds a further source of electrical stress on driven machines (Oshevire, Eyenubo, and Amayo, 2017), a consideration that grows as smart grid architectures with high renewable penetration extend into industrial sites (Adenuga, 2022).

Hose reel, hawser winch, and capstan drives use grease lubricated gearboxes and open gear sets, whose performance evaluation follows the same development and testing logic applied to purpose built mechanical equipment generally (Bello, Adama, Tawose, and Bolaji, 2022). Pedestal cranes serving the terminal carry slew ring bearings whose failure history in offshore service is well documented, and whose degradation feeds directly into the risk pathways identified for lifting and rigging operations (Arumosoye and Obriki, 2022) and into risk models developed for crane installation and heavy lift engineering (Obogo, Arumosoye, and Obriki, 2020b). Finally, mooring system components such as chain stopper pins and fairlead bearings are greased and safety critical.

3.2 Dominant Failure Modes

Failure mode and effects analysis across this population shows a consistent pattern. Rolling contact fatigue and wear of raceways and rolling elements dominate for main bearings and slew rings, aggravated by low speed boundary lubrication, oscillatory motion that produces false brinelling and fretting at preferred positions, and structural deflection of large diameter races. Seal degradation admits seawater, salt, and sand, which corrode raceways and turn grease into an abrasive lapping compound; water washout then depletes the grease charge. The marine corrosion pathway is well characterized in the integrity literature, where corrosion risk assessment for process equipment establishes that chloride bearing environments drive localized attack at rates strongly dependent on temperature and exposure cycling (Atta, Tofah, Kankam, and Adenuga, 2020), and where the inhibitor literature demonstrates that protection of steel surfaces in aggressive media depends on maintaining an intact adsorbed film, which is precisely the function grease performs and loses as it degrades (Atta, Asomani, and Adenuga, 2018).

Grease degradation itself, through oxidation during long service intervals, thickener breakdown under churning, and incompatibility introduced by regreasing with the wrong product, is a first order failure cause rather than a background condition. Gear tooth wear and scuffing affect winch and slew drive open gears where grease films are marginal. For product swivels, bearing distress and seal wear interact: Bearing wear increases runout, runout accelerates seal wear, and seal leakage of crude into the bearing cavity contaminates the grease, an interaction that grease analysis is uniquely positioned to detect because product hydrocarbons appear directly in the grease signature. Structured factor analysis methods of the kind applied to mechanical equipment performance evaluation are useful in ranking which of these interacting variables actually dominate observed degradation on a given machine population (Bello, Tawose, Adama, and Bolaji, 2022).

3.3 Why Conventional Monitoring Falls Short

Applying the reliability centered maintenance detectability test to these failure modes exposes the monitoring gap. Vibration analysis requires defect impact energy at measurable frequency; at SPM main bearing speeds the fundamental defect frequencies are in the millihertz range and early damage is undetectable, while wave excitation contaminates the low frequency band. Acoustic emission and stress wave methods improve detection on slew rings but demand permanently mounted sensors, expert interpretation, and cabling that is hard to sustain on a buoy in the splash zone. Thermography sees only late stage distress in massive, thermally sluggish components. Geometric methods such as rocking tests and wear down measurements are valuable but infrequent, weather dependent, and sensitive only to accumulated wear rather than active degradation rate. Internal visual inspection requires disassembly that itself introduces risk and, for main bearings and swivels, may require export shutdown. Oil analysis is inapplicable.

Two further factors compound the problem. First, inspection quality on infrequent, physically demanding, weather constrained tasks is subject to well documented human error mechanisms in high risk industrial activity (Obriki and Arumosoye, 2020), so infrequent inspection is not merely sparse but variable. Second, hazard identification and risk control practice consistently finds that risks observed rarely are ranked lower than their true consequence warrants (Obogo, Uduokhai, and Ozobu, 2019). The consequence, observed across the industry, is that grease lubricated export assets have historically occupied the worst quadrant of the monitoring matrix: Highest consequence, lowest detectability.

3.4 Consequence Framing and Criticality

Because intervention on these assets is expensive and disruptive, criticality assessment must be quantitative rather than intuitive. Structured supplier and operational risk assessment practice provides a workable pattern for allocating consequence across asset elements and responsible parties (Akin-Oluyomi, Atima, and Akinleye, 2023b), real time risk assessment dashboards demonstrate how such assessments are kept current rather than annual (Filani, Nnabueze, Ike, and Wedraogo, 2022), and governance oriented models for contractor and facility safety performance show how criticality judgments are made durable through explicit ownership (Arumosoye and Obriki, 2020; Obogo, Obriki, and Arumosoye, 2022). The criticality tiering proposed in Section 5.2 follows this pattern.

Table 1: Grease lubricated offshore crude export assets, failure behavior, and monitoring constraints

Asset	Typical speed and motion	Dominant failure modes	Conventional monitoring limitation
SPM/CALM buoy main bearing	Below 1 rpm, oscillatory weathervaning	Raceway wear, corrosion, false brinelling, grease loss	Vibration ineffective at speed; internal inspection needs off-station work
Turret and product swivel bearings	Very low speed, continuous or oscillatory	Bearing wear, seal leakage, product ingress into grease	Sealed assembly, no oil system, limited access
Loading arm slew rings and swivel joints	Intermittent articulation	False brinelling, seal wear, water and salt ingress	Intermittent duty defeats vibration trending
Export pump and motor bearings (grease packed)	1500 to 3600 rpm	Fatigue, grease degradation, overgreasing damage	Vibration works but grease condition unseen until damage
Winch and hose reel gear drives	Low speed, high torque, intermittent	Gear wear, water ingress, grease hardening	Enclosed or open gears without oil sump to sample
Pedestal crane slew bearings	Below 2 rpm, oscillatory	Raceway spalling, bolt and seal issues	Slow speed vibration limits; grease sampling already industry practice

4. Grease Analysis Technology

4.1 Sampling: The Governing Discipline

Grease analysis succeeds or fails at the sampling step. Because grease does not mix, a sample represents only the location from which it was drawn, and the diagnostic objective is precisely to reach grease that has been in the load zone. ASTM D7718 defines three practical approaches that map well to export assets. Passive purge sampling collects grease expelled from vent ports, labyrinth gaps, or purge fittings during routine regreasing; it is the least intrusive method and suits export pump bearings and swivel joints, with the discipline that the sample is taken after old grease begins to emerge and is identified as purge material. Active thief sampling draws grease through an existing fitting or drilled and plugged sample port using a syringe sampler with a tube extended toward the bearing cavity; on

SPM main bearings and crane slew rings, dedicated sample ports arranged at intervals around the circumference allow the load zone sector to be sampled deliberately, because damage on large slow bearings is position specific. Opportunistic sampling collects grease from exposed surfaces, seal lips, or opened housings during planned maintenance; it is the least controlled method but valuable for baselining and for post-inspection correlation.

Program design principles follow directly. Sampling locations must be fixed, labeled, and photographed so that successive samples are comparable. Sample size targets of 1 to 5 grams suit modern methods. Fresh grease reference samples from every product in use on the terminal must be held by the laboratory, since all in-service results are interpreted as deviations from the reference. Cross contamination between points is controlled with single use samplers. Each sample must carry metadata: Asset and point identity, grease product and batch, time since last regrease, quantity added, operating context such as recent storm loading or tanker throughput, and the position of the buoy or crane at sampling. Interpretation without this context is guesswork.

4.2 Procedure Control and Quality Assurance

Because the entire diagnostic chain depends on execution consistency by rotating offshore crews, the sampling method must be written and controlled as a formal standard operating procedure rather than as guidance. The evidence that documented procedures function as strategic operational assets rather than administrative overhead is directly applicable (Eyetsemitan, Oyeleye, Ambali, and Fadayomi, 2022), as is the finding that procedure development in small teams succeeds when it follows a lightweight structured improvement cycle rather than a heavyweight methodology (Ambali, Eyetsemitan, Oyeleye, and Fadayomi, 2021). Cycle time redesign work using structured process improvement demonstrates how repetitive operational sequences are shortened without loss of control, which matters when sampling must be absorbed into an existing regreasing round (Oyeleye, Eyetsemitan, Ambali, and Fadayomi, 2022), and data driven optimization models show how bottlenecks in such sequences are identified from operational data rather than assumption (Efobi, Akinleye, and Fasawe, 2022b). Where regulatory or contractual obligations attach to lubrication and integrity records, translating those requirements into concrete workflow steps rather than policy statements is the established route to compliance in practice (Eyetsemitan, Ambali, Oyeleye, and Fadayomi, 2021).

Assurance over the sampling process itself should be handled as an internal audit function rather than left to the sampling team, following established practice in internal quality, health, safety, and environmental audit systems for industrial engineering operations (Obogo, Arumosoye, and Obriki, 2020a). The same quality assurance logic that governs inspection standards on major projects applies to the grease program: A method is only as good as the documented competence and verification regime around it (Atta, Adjaklo, Asomani, and Adenuga, 2022).

4.3 Laboratory Test Slate

A 2023 state of practice test slate for export assets combines machine health and grease health parameters. For machine health, elemental spectroscopy by ICP after digestion or dilution quantifies wear metals: Iron, chromium, and nickel from races and rolling elements; copper, lead, and tin from cages and bushings; and contaminant elements such as silicon and aluminum indicating sand and dust, with sodium and magnesium marking seawater. Ferrous debris measurement, either by magnetometer based instruments or by the D7918 procedure, captures the larger fatigue particles that spectroscopy under-reports, which is essential because rolling contact fatigue on slow bearings generates coarse debris. Analytical ferrography on solvent dispersed grease characterizes particle morphology, distinguishing cutting wear from fatigue spalls, corrosion products, and spheres, and thereby identifies the active failure mechanism. For grease health, FTIR spectra trended against the fresh reference reveal oxidation, base oil loss, water, and, critically for swivels, crude oil ingress through its distinct hydrocarbon signature; cone penetration or the D7918 extrusion flow value tracks consistency change; Karl Fischer titration quantifies water; and linear sweep voltammetry measures remaining primary antioxidant, giving a direct measure of remaining grease life. Bleed and oil separation tests, where sample volume allows, indicate whether the grease can still release oil to the contact.

Table 2: Core diagnostic parameter set for offshore crude export grease analysis

Parameter	Method basis	What it indicates	Primary export asset relevance
Wear metals (Fe, Cr, Ni, Cu, Pb, Sn)	ICP spectroscopy, ASTM D5185 adapted	Active wear of races, elements, cages	All bearings; trend per point
Ferrous debris index	Magnetometry / ASTM D7918	Coarse fatigue debris missed by ICP	Main bearings, slew rings, gears
Particle morphology	Analytical ferrography, D7684 guidance	Failure mechanism identification	Root cause on alarmed points
Contaminant elements (Si, Al, Na, Mg)	ICP spectroscopy	Sand, dust, seawater ingress	Seal condition on all assets
Water content	Karl Fischer, ASTM D6304 with extraction	Seal failure, washout risk, corrosion	Splash zone assets, loading arms
Oxidation / carbonyl	FTIR vs fresh reference, E2412 practice	Thermal and oxidative grease aging	Long interval assets, motor bearings
Remaining antioxidant	Voltammetry, D6971 adaptation	Remaining grease life	Regrease interval optimization
Consistency / flow	ASTM D1403 or D7918 extrusion	Shear breakdown or hardening	Churning assets, incompatibility checks
Crude / product ingress	FTIR hydrocarbon signature	Swivel seal leakage into bearing cavity	Product swivels, toroid bearings
Grease identity check	FTIR fingerprint vs reference	Wrong grease or mixing events	All points after any regreasing

4.4 Field Screening

Offshore logistics reward a two tier structure in which simple field screens performed by terminal technicians triage samples and events between laboratory cycles. Practical field methods in 2023 included portable ferrous density meters reading directly on grease filled sample pots, crackle or pressure cell water screens, visual and tactile checks against a fresh grease comparator card for color, bleed, and texture, and consistency screening with pocket penetrometers. Field screening does not replace the laboratory slate; it shortens the reaction time when a purge emerges black, gritty, or fluid, and it builds the sampling habit into routine regreasing rounds. The design constraints on offshore field instrumentation, namely limited power, intermittent connectivity, and unattended operation between crew changes, are the same constraints that shape energy autonomous sensing research (Asiedu and Quainoo, 2023a). Where field screening data is transmitted to shore, the transmission path becomes part of the operational technology estate and inherits its security requirements (Jimoh, Abolle-Okoyeagu, Ahmed, and Lawal, 2023).

5. The Predictive Maintenance Concept

5.1 Concept Statement

The concept is stated as follows. Every grease lubricated critical asset on the crude export path is assigned fixed sampling points, a defined sampling interval, and a laboratory test slate. Results are trended per point against fresh grease references and statistically derived limits. Alarm conditions trigger a defined diagnostic escalation, and maintenance actions, from purge regreasing through seal renewal to bearing replacement planning, are initiated by grease condition rather than by calendar or by failure. Grease analysis thereby becomes the primary condition monitoring technology for this asset class, complemented where feasible by geometric measurements, acoustic emission, and inspection, and integrated into the terminal reliability program under ISO 17359 program design and ISO 14224 data structures.

5.2 Criticality Based Sampling Design

Sampling intensity follows criticality. Tier 1 covers assets whose failure stops export and whose replacement is a major project: SPM main bearings, turret bearings, and product swivels. These receive multiple circumferential sampling points, quarterly laboratory analysis, monthly field screening, and mandatory sampling after storm events, mooring incidents, or abnormal turntable behavior. Tier 2 covers assets whose failure curtails export or presents major safety exposure with available but disruptive replacement paths: Loading arm slew rings and swivel joints, export pump and motor bearings, and crane slew rings, sampled semiannually with laboratory analysis and quarterly field screening. Tier 3 covers remaining greased assets, winch drives, actuators, and sheaves, sampled annually or on opportunity.

Intervals are then tuned by evidence: The interval must be shorter than the shortest credible P-F interval for the dominant failure mode, and observed wear rate trends justify tightening or relaxing frequency per point. Experience from analogous slow bearing programs indicates P-F intervals of many months to years for fatigue driven modes, which quarterly sampling comfortably covers, but far shorter intervals for water ingress driven corrosion, which is why event triggered sampling after seal damaging incidents is mandatory rather than optional. The tiering itself should be maintained as a live artifact within the asset lifecycle performance record rather than as a one time engineering study, consistent with digital transformation models that treat lifecycle performance management as a continuously updated data product (Adelanwa, Basnet, and Anene, 2023a). Program maturity should be assessed explicitly and improved deliberately, following organizational learning based maturity models developed for continuous performance improvement in industrial settings (Arumosoye and Obriki, 2021).

5.3 Limits, Trending, and Alarm Philosophy

Grease analysis limits cannot be imported from oil analysis tables because concentrations depend on grease charge size, sampling position, and purge history. The recommended philosophy is per point statistical trending: After a baselining period of four to six samples, each parameter receives a caution limit at a defined deviation above the point baseline, commonly mean plus two standard deviations or a fixed multiple for skewed parameters such as ferrous debris, and a critical limit anchored either at mean plus three standard deviations or at absolute values associated with known damage states in comparable bearings. Rate of change matters as much as level: A ferrous index doubling between quarterly samples is actionable even below the absolute caution line.

Alarms escalate diagnostically before they escalate operationally: A caution triggers a confirmation resample and field screen; a confirmed caution adds ferrography to identify mechanism; a critical result triggers multi-point sampling to localize the damage sector, correlation with geometric measurements, and entry of the asset into failure development monitoring with shortened intervals. This staged logic protects the program from the false alarms that destroy operator confidence in new monitoring technologies. The design principle mirrors mature practice in industrial leading indicator systems, where escalation is graduated and the indicator population is deliberately broad (Arumosoye and Obriki, 2019; Obogo, Arumosoye, and Obriki, 2021; Obriki and Arumosoye, 2019), and where accumulated observation supports early identification of high risk conditions before consequence is realized (Obriki and Arumosoye, 2023; Obriki, Arumosoye, and Obogo, 2023).

5.4 Decision Integration

Grease analysis outputs map onto four maintenance decisions. First, regrease optimization: Antioxidant depletion, oxidation trend, and consistency change set the regreasing interval and quantity per point, replacing generic time based schedules and avoiding both starvation and the churning damage caused by overgreasing. Second, seal and ingress management: Rising silicon, sodium, water, or product hydrocarbon signatures direct seal inspection and renewal before contamination converts into wear, which is the single most valuable early intervention on splash zone assets. Third, damage management: Confirmed wear debris trends initiate engineering evaluation, load management such as berthing envelope restrictions for a degraded SPM bearing, spares strategy review, and replacement planning on a timescale the business can absorb. Fourth, verification: Post-maintenance samples confirm that a purge, seal change, or bearing replacement returned the point to baseline, closing the loop.

Each decision consumes grease data alongside operating context, which is why results must land in the maintenance management system against ISO 14224 aligned equipment and failure mode records rather than in a standalone laboratory portal, consistent with asset lifecycle management models that tie condition data, inventory visibility, and maintenance decisions into a single record structure (Okonkwo, Mayo, and Okeke, 2023). Where the condition record crosses organizational boundaries into procurement and logistics, the integration is a systems engineering task rather than a reporting task (Okonkwo, Ahiaeke Patrick, Okeke, and Mayo, 2023), and end to end visibility frameworks show that traceability across organizational boundaries is what makes such data trustworthy in use (Nnabueze, Ike, Olatunde-Thorpe, Aifuwa, Oshoba, Ogbuefi, and Akokodaripon, 2021). The resulting reporting layer should be built as a lifecycle performance capability that measures outcomes rather than merely displaying results (Adelanwa, Basnet, and Anene, 2023a), and visualization research confirms that presentation format materially affects whether such evidence changes decisions (Babatope, Akokodaripon, Akinleye, and Okoruwa, 2023).

5.5 Worked Illustration: SPM Main Bearing

An SPM buoy main bearing is fitted during a planned dry docking with eight circumferential sample ports and purge routing. Baseline samples establish per port references for iron, ferrous index, sodium, water, and FTIR spectra against the fresh grease reference. In routine operation, quarterly samples show stable chemistry for two years. Following a severe storm season, the port aligned with the dominant mooring load direction shows sodium and water elevated above caution and, one quarter later, a threefold rise in ferrous index with ferrography showing corrosion products and early fatigue platelets. The staged response localizes damage to one sector, correlates with a small increase in measured bearing wear down, and supports a decision package: Increased purge regreasing to flush the sector, seal remediation at the next weather window, monthly sampling of the affected ports, and initiation of long lead bearing spares review. Export continues under a managed berthing envelope. Without grease analysis, the first indication would plausibly have been turntable roughness or seizure at a time not of the operator's choosing.

5.6 Relationship to Other Condition Evidence

Grease analysis is not proposed as a replacement for geometric survey, inspection, or structural monitoring, but as the connective evidence that makes those activities purposeful. The integration pattern is the one established in corridor and utility asset monitoring, where independent evidence streams are fused against a shared spatial and asset reference so that each observation narrows the interpretation of the others (Dagodzo and Ahiaeke Patrick, 2021b; Dagodzo and Ahiaeke Patrick, 2021a). Applied to an SPM buoy, a grease result identifying an affected sector tells the inspection team where to look, while a rocking test result tells the interpretation team how far degradation has progressed. Neither alone supports a confident intervention decision.

6. Implementation Framework

6.1 Program Establishment

Implementation follows six steps. Step one is an asset and failure mode register: Enumerate every greased export asset, its grease products, access points, and monitoring objectives derived from failure mode analysis. Step two is sampling engineering: Design and install sample ports where absent, standardize samplers and containers, and write point specific procedures with photographs. Step three is laboratory establishment: Select a laboratory with demonstrated in-service grease capability on the D7718 and D7918 method families, lodge fresh grease references, and agree reporting formats, units, and turnaround. Step four is baselining: Two to four rounds across all points before limits are enforced, concurrent with technician training to at least ISO 18436 category style competence in lubrication analysis. Step five is limit setting and system integration. Step six is governance: A standing reliability review that owns trends, audits sampling quality, and reports leading indicators such as percentage of points sampled on schedule and caution to resolution time.

Two implementation risks deserve explicit treatment. The first is adoption. Introducing a new monitoring technology into an established offshore maintenance routine is a change management problem before it is a technical one, and structured lean change adoption frameworks provide the appropriate treatment for small operational teams absorbing new workflows (Eyetsemitan, Ambali, Oyeleye, and Fadayomi, 2023a), particularly where the change combines procedural and digital elements. The second is validation. Before the program is trusted for Tier 1 decisions, the end to end chain from sampling through laboratory reporting to the maintenance system should pass a structured acceptance test with defined pass criteria (Eyetsemitan, Ambali, Oyeleye, and Fadayomi, 2023b).

Where the terminal sits within a multinational operating structure, the governance arrangements that determine who owns limits, who authorizes escalation, and who funds intervention should be settled in advance, following established practice in project governance for multinational infrastructure operations (Amayo, Owulade, and Isi, 2023a). Comparable programs in regulated and high consequence sectors show that risk management and compliance frameworks must be defined alongside the technical scope rather than after it (Amayo, Owulade, and Isi, 2023b), and multi-stakeholder governance alignment research addresses the joint venture case directly, in which several partners must agree who owns a monitoring obligation before it can be discharged (Eyetsemitan, Ambali, Oyeleye, and Fadayomi, 2020). Capital project delivery models for high risk facilities further demonstrate the value of treating monitoring capability as a lifecycle deliverable rather than an operational afterthought (Aminu-Ibrahim, Ogbete, and Ambali, 2019).

6.2 Competence, Organization, and Human Factors

Three organizational factors decide success. Sampling quality depends on the motivation and skill of the technicians who take samples; embedding sampling in regreasing rounds, returning laboratory results to the samplers with interpretation, and recognizing detections builds the necessary ownership, and workforce safety training research shows that operational behaviors persist only when training is reinforced by routine rather than by campaign (Obriki, Obogo, and Arumosoye, 2022a). Interpretation competence must sit onshore with a nominated reliability engineer who accumulates the terminal specific pattern library, because grease data is context dependent and generic laboratory comments are insufficient for Tier 1 decisions. Management commitment must survive the baselining period, during which the program produces data but few dramatic saves; leadership research in project and construction organizations shows that visible senior sponsorship is what carries such initiatives through their low yield phase (Obogo, Nwafor, and Ozobu, 2023; Obriki and Arumosoye, 2021), and studies linking management observation frequency to cultural outcomes confirm that sponsorship must be demonstrated in the field rather than announced (Obriki and Arumosoye, 2019).

The human factors of the work itself should not be underestimated. Sampling on an exposed buoy deck or a crane pedestal introduces the incident exposure characteristic of industrial maintenance environments, best managed through the prevention models developed for that setting (Obogo, Obriki, and Arumosoye, 2021), and all such work must sit inside the occupational safety management systems established for oil and gas maintenance activity (Obogo, Arumosoye, and Obriki, 2020c). Tropical offshore terminals impose thermal exposure that degrades both technician performance and sampling discipline, which merits deliberate scheduling controls of the kind proposed in integrated heat stress risk modeling for industrial operations in extreme environments (Arumosoye and Obriki, 2018). Human error causation modeling further indicates that procedural steps performed rarely, under time pressure, and in discomfort are the steps most likely to be omitted (Obriki and Arumosoye, 2020), which argues for short, well rehearsed sampling routines rather than comprehensive ones.

6.3 Integration with Safety and Emergency Management

The escalation path from a critical grease result to a possible export curtailment intersects the terminal emergency and response readiness structure, which must recognize condition based triggers alongside event based ones (Arumosoye and Obriki, 2023). Where interventions require lifting, rigging, or crane work, as most bearing and seal interventions on export assets do, the risk pathways and controls for those operations govern the execution plan (Arumosoye and Obriki, 2022; Obogo, Arumosoye, and Obriki, 2020b). Where contractors perform the work, contractor safety performance governance determines whether the controls are actually applied (Arumosoye and Obriki, 2020), compliance systems research shows how that oversight is verified rather than assumed (Obogo, Uduokhai, and Ozobu, 2021), and multi-contract facility safety governance models set out how it is structured across parties (Obogo, Obriki, and Arumosoye, 2022). Condition findings that indicate an imminent loss of function must also connect to emergency preparedness and evacuation arrangements where the affected asset is manned during transfer operations (Obriki, Obogo, and Arumosoye, 2022b). Finally, findings that reveal a latent failure mechanism should be routed into the organizational learning process, not only into the maintenance backlog (Obriki and Arumosoye, 2022).

6.4 Digital Architecture and Data Governance

Grease results only create value when they reach the systems where maintenance and procurement decisions are made, which makes the data pathway a design concern rather than an afterthought. The condition record should be structured so that it is machine readable, asset referenced, and available to both the reliability function and the materials organization, following the integration principles established for linking information systems engineering with supply chain operations in energy environments (Okonkwo, Ahiaeke Patrick, Okeke, and Mayo, 2023). Enterprise resource planning integration research documents both the performance gains and the adoption difficulties involved, particularly where spatially referenced asset data must be reconciled with transactional procurement records (Ahiaeke Patrick, Okonkwo, Mayo, and Okeke, 2020), and business intelligence work in manufacturing procurement demonstrates how the resulting data is turned into decisions rather than reports (Akinleye, Okoruwa, Babatope, and Akokodaripon, 2023).

Governance of the data itself matters as much as its movement. Risk based business intelligence architecture provides the pattern for exposing condition data to decision makers without exposing it indiscriminately (Mbonu, Aliliele, Iwuanyanwu, and Uzoka, 2021a); frameworks for embedding compliance controls into digital transformation of the supply chain show how audit requirements are satisfied by design rather than by retrospective reconstruction (Mbonu, Iwuanyanwu, Aliliele, and Uzoka, 2020a); and general control automation research establishes how evidence of control operation is generated as a by-product of the workflow rather than assembled before an audit (Mbonu, Aliliele, Iwuanyanwu, and Uzoka, 2022). Enterprise log analytics practice demonstrates the same principle for the technical record, in which the trail of who recorded what and when is retained automatically (Mbonu, Iwuanyanwu, Uzoka, and Oluoha, 2019). Where operators progress toward digital twin representations of export equipment, the discipline established for tiered digital twins applies directly, namely that the twin is only as trustworthy as the provenance and fidelity of the measurements feeding it (Komi and Adeniji, 2023).

6.5 Operational Technology Security

Because these pathways connect operational technology to enterprise systems, they carry the security exposure documented for converged environments. Architectural work on information technology and operational technology convergence in regulated energy networks sets out the segmentation and governance principles that a condition monitoring data path should respect (Adegbite, Adebayo, and Ahmed, 2022), and systematic review of operational technology network security in utilities establishes the compliance baseline against which such designs are assessed (Adegbite, Adebayo, and Ahmed, 2020). Security audit and enterprise risk assessment frameworks provide the means of confirming that the design as built matches the design as specified (Dosunmu and Ogundele, 2019), while intrusion detection and prevention research addresses the residual case in which it does not (Dosunmu and Ogundele, 2020). Reviews of anomaly detection in industrial control systems establish that monitoring data streams are themselves an attack surface requiring detection coverage (Adebayo, Adegbite, and Ahmed, 2023; Adegbite, Adebayo, and Ahmed, 2023), and adversarial machine learning research warns that analytics layers built on those streams can be manipulated as readily as the streams themselves (Adebayo, Adegbite, and Ahmed, 2022).

Zero trust architecture research provides the access model appropriate to a data path that spans an offshore facility, a third party laboratory, and a corporate maintenance system (Ahmed, Adegbite, and Adebayo, 2021), identity centric zero trust models developed for enterprise security governance address the same problem from the access control side (Ogbole, Okoruwa, Fadayomi, Abolaji, Edivri, and Akeju, 2021), and identity and access management integration research addresses the hybrid case in which offshore, corporate, and third party laboratory systems must interoperate (Mbonu, Aliliele, Iwuanyanwu, and Uzoka, 2020). Research on security in sensor driven critical infrastructure addresses the specific exposure introduced by field instrumentation (Jimoh, Abolle-Okoyeagu, Ahmed, and Lawal, 2023), privacy centric security engineering establishes how such systems are designed rather than patched (Okoruwa, Fadayomi, Akeju, Edivri, Ogbole, and Abolaji, 2020), and continuous monitoring for cloud misconfiguration addresses the most common practical failure once laboratory reporting moves to hosted platforms (Aliliele, Mbonu, and Iwuanyanwu, 2023a). Where laboratory results arrive through programmatic interfaces, application programming interface governance and risk prioritization apply directly (Aliliele, Mbonu, and Iwuanyanwu, 2023b). The practical implication for an export terminal is modest but real: Grease results should not be allowed to become an unmanaged data channel.

6.6 Spares, Procurement, and Contracting Strategy

The connection between condition knowledge and spares strategy is direct. Inventory availability models for energy facilities show that plant uptime depends on holding the right long lead spares (Okonkwo, Ogunwole, and Okeke, 2018b); materials readiness frameworks demonstrate that maintenance driven supply chain performance improves sharply when procurement is triggered by early condition indicators rather than by failure (Okonkwo, Agbabiaka, Ogunwole, Mayo, and Okeke, 2021); and strategic procurement optimization work in oil and gas operations formalizes the resulting link between anticipated maintenance demand and sustained operational uptime (Okonkwo, Ogunwole, and Okeke, 2018a). Grease analysis supplies exactly the early indicators these models require. Predictive analytics applied to procurement demand forecasting shows how the resulting signal is converted into a funded plan rather than an aspiration (Akin-Oluyomi, Atima, Akinleye, and Okoruwa, 2023; Aifuwa, Oshoba, Ogbuefi, Ike, Nnabueze, and Olatunde-Thorpe, 2020), and early warning models developed for shortage prone critical supply categories demonstrate how a detected risk is escalated into a procurement response within a defined time frame (Eze, Anene, and Akinleye, 2022a).

Vendor and lead time risk on long lead bearing, seal, and swivel items should be assessed with the predictive discipline established in procurement risk practice (Akin-Oluyomi, Atima, and Akinleye, 2023b), and relationships with those few qualified suppliers should be managed as strategic rather than transactional, following supplier relationship management research in complex global chains (Ike, Ogbuefi, Nnabueze, Olatunde-Thorpe, Aifuwa, Oshoba, and Akokodaripon, 2021; Akinleye and Adeyoyin, 2022b). Where selection among suppliers or repair yards is contested, structured data driven vendor evaluation methods reduce the discretion involved (Ahiaeke Patrick, Okonkwo, Mayo, and Okeke, 2021), and negotiation optimization models address the commercial exposure that arises when a single qualified supplier holds an urgent requirement (Akinleye and Adeyoyin, 2022a). For terminals operating under strict national or contractual compliance regimes, the procurement route for emergency replacement items should be pre-established rather than improvised under outage pressure (Okonkwo, Ogunwole, Mayo, and Okeke, 2021; Okonkwo, Ogunwole, Okeke, and Mayo, 2019), and process automation shortens the interval between a condition decision and a placed order (Akinleye and Adeyoyin, 2021). Lean supply chain practice indicates that the resulting inventory should be sized against demonstrated condition risk rather than held indiscriminately (Ike, Ogbuefi, Nnabueze, Olatunde-Thorpe, Aifuwa, Oshoba, and Akokodaripon, 2022), and sustainable and green procurement frameworks show how environmental criteria are incorporated without displacing availability (Efobi, Akinleye, and Fasawe, 2022a; Akin-Oluyomi, Atima, and Akinleye, 2023a). Finally, the terminal should hold an explicit view of its own supply resilience for these items, of the kind captured in supply chain resilience index frameworks (Efobi, Akinleye, and Fasawe, 2023; Ogunwole, Okonkwo, Agbabiaka, Mayo, and Okeke, 2021).

6.7 Assurance, Audit, and Regulatory Maturity

A monitoring program that informs export availability decisions will eventually be examined by auditors, insurers, class societies, and terminal vetting inspectors, and it should be designed for that examination. Technology enabled risk assessment frameworks for internal audit establish how condition evidence is made auditable, namely through traceable data lineage and documented judgment rather than through volume of reporting (Akomolafe and Agu, 2018). The aviation safety oversight literature offers the closest available analogue for a regulated, high consequence, evidence driven assurance regime. Adaptive safety management system implementation models show how formal safety systems are made workable in resource constrained operating contexts rather than merely mandated (Adeyelu, 2019); predictive compliance monitoring frameworks demonstrate how routine operational data is mined for systemic risk signals ahead of formal audit (Adeyelu, 2018); comparative benchmarking models establish how compliance performance is measured across comparable operators (Adeyelu and Dagodzo, 2022); regulatory evidence frameworks show how a technical finding is converted into a defensible enforcement or corrective record (Adeyelu, 2022); and risk tiered oversight models demonstrate how scrutiny is proportioned to consequence rather than applied uniformly (Adeyelu, 2023). Quantified hazard assessment models illustrate how recurring operational risks are expressed in terms that support intervention decisions (Adeyelu, 2020), and framework approaches to persistent physical encroachment show the value of standardized corrective action over case by case response (Adeyelu, 2021). A grease analysis program that adopts these habits, traceable evidence, proportionate oversight, benchmarked performance, and standardized corrective action, will be defensible under scrutiny.

6.8 Economics

The cost side of the program is modest. For a representative terminal with one SPM, one loading arm pair or offloading system, export pumps, cranes, and winches, the recurring cost comprises on the order of one hundred to two hundred laboratory samples per year, field screening consumables, a fractional full time equivalent for sampling within existing rounds, and a fractional onshore engineering resource, with a one time investment in sample port installation and training. The benefit side is dominated by avoided deferment. A single avoided unplanned export shutdown of several days, at deferment values typical of mid-sized terminals, exceeds the lifetime cost of the program by one to two orders of magnitude; a single deferred or de-risked SPM main bearing replacement, converted from emergency response to planned campaign, is similarly decisive.

Presenting that case internally requires the language of capital allocation rather than of engineering. Decision models for capital allocation using financial analytics provide the appropriate framing for a small recurring expenditure that protects a large revenue stream (Lawal and Oduleye, 2021a), working capital and cash flow optimization models capture the value of converting unplanned emergency spend into scheduled spend (Oduleye and Medon, 2023a; Tonoyan, Dada, and Ayivi-Donkor, 2021b), and analytics driven enterprise value models address the same question where the constraint is deployable capital rather than cost (Lawal and Oduleye, 2018a). Simulation based assessment of process optimization and its financial impact offers a route to quantifying the benefit before the program has generated its own evidence (Tonoyan, Dada, and Ayivi-Donkor, 2022b), demand and asset valuation forecasting methods support the deferment assumptions on which the case rests (Tonoyan, Dada, and Ayivi-Donkor, 2021a; Tonoyan, Dada, and Ayivi-Donkor, 2023), and quantitative models for measuring the strategic impact of financial analysis show how the realized benefit is subsequently attributed to the program that produced it (Oduleye and Medon, 2023b; Medon and Oduleye, 2022). Where the terminal wishes to detect deterioration in its own cost and consumption patterns, anomaly detection methods developed for operational time series apply directly (Atakpa and Fobellah, 2023), and geospatial predictive methods offer a route to comparing performance across terminals in a portfolio (Tonoyan, Dada, and Ayivi-Donkor, 2022a).

Secondary benefits include extended regreasing intervals with reduced grease consumption and disposal, reduced overgreasing damage to motor bearings, seal renewals performed at weather windows rather than emergencies, and an integrity evidence trail supporting insurance, class, and vetting reviews. Even under conservative assumptions about detection probability, the expected value is strongly positive, which is the economic signature of a low cost monitoring technology applied to a high consequence, previously unmonitored asset class.

6.9 Environmental Performance and Lifecycle Considerations

The program also carries environmental and lifecycle benefits that increasingly attract independent scrutiny. Condition based regreasing reduces grease consumption and the volume of contaminated waste requiring offshore handling and shipment, which is precisely the kind of operational discipline that circular economy decision frameworks link to measurable environmental performance (Okojie and Abioye, 2020). Avoided failures avoid spill risk at the export interface, which sits alongside produced water and other discharge streams as a primary offshore environmental exposure (Falegan and Aniebonam, 2022; Falegan and Aniebonam, 2023). Automated reporting of such performance was already emerging by 2023, with artificial intelligence assisted auditing of environmental, social, and governance metrics in infrastructure operations providing the reporting pattern (Okojie, Filani, Ike, Okojokwu-Idu, Nnabueze, and Ihwughwavwe, 2023), predictive models for monitoring emissions and infrastructure risk demonstrating the analytical layer (Okojie, Ike, Idu, Nnabueze, Filani, and Ihwughwavwe, 2023), and blockchain enabled compliance management systems illustrating how such reporting is made tamper evident in energy projects (Abioye, Okojie, Filani, Ike, Idu, Nnabueze, Okojokwu-Idu, and Ihwughwavwe, 2023).

At the capital planning level, extending the service life of a five meter forged steel bearing avoids a substantial embodied material and energy burden as well as a capital cost, and sustainable materials selection and energy efficiency research provides the framework for recognizing that benefit rather than treating it as incidental (Ogbete, Aminu-Ibrahim, and Ambali, 2020). More broadly, lifecycle performance evaluation of purpose built facilities demonstrates that assets designed and maintained against long horizon performance metrics outperform those managed against annual budgets (Ogbete, Aminu-Ibrahim, and Ambali, 2023), sustainable infrastructure modeling shows how such long horizon criteria are embedded at design stage (Aminu-Ibrahim, Ogbete, and Ambali, 2018), and risk managed construction strategies for complex regulated facilities show how those commitments survive execution pressure (Ogbete, Aminu-Ibrahim, and Ambali, 2021), which is the correct frame for an export path that must survive storm seasons. Programmatic strategy research on large scale energy deployment reinforces that such long horizon commitments require a program, not a project (Yeboah and Ike, 2020).

7. Discussion: Limitations and Research Needs

7.1 Limitations

The concept has real limitations that a mature program acknowledges. Sampling representativeness remains the fundamental uncertainty: Grease near a port may not reflect the worst sector of a five meter bearing, which is why multi-point designs, purge stream sampling, and correlation with geometric measurements are built into the framework rather than treated as refinements. Quantitative limits are asset specific and transfer poorly between installations; the statistical per point philosophy manages this but requires patience during baselining. Laboratory method variability between providers is larger for grease than for oil, so a program should qualify one laboratory and hold it, using round robin checks when changing. Detection is not guaranteed for all modes: Sudden overload damage from a mooring incident generates debris only after the fact, so grease analysis complements rather than replaces incident triggered inspection. Data interpretation depends on records of every regreasing event, since each grease addition dilutes the diagnostic signal; disciplined lubrication record keeping is a precondition, not a nicety. Finally, the program depends on sustained execution by rotating crews, which is an organizational vulnerability rather than a technical one, and one that the change management and training literature suggests will require continuing attention rather than a single implementation effort (Eyetsemitan, Ambali, Oyeleye, and Fadayomi, 2023a; Obriki, Obogo, and Arumosoye, 2022a).

7.2 Research and Development Needs

The first research group is online grease condition sensing, particularly dielectric, ultrasonic, and optical probes embedded in bearing cavities, which would convert periodic sampling into continuous monitoring for Tier 1 assets, following the trajectory already demonstrated by sensor based fault detection architectures in other mechanical plant systems (Sunday and Omoegun, 2022) and by instrumented condition monitoring of conventional rotating machinery (Omoegun, Sunday, Essien, and Oluokun, 2023). The viability of such probes in splash zone and unattended locations depends on progress in energy autonomous and intermittently powered sensing, where reliability under uncertain power availability is the governing constraint (Asiedu and Quainoo, 2023a; Asiedu and Quainoo, 2023b), and where the placement of interpretation between local and central layers remains an open architectural question (Komi and Ganiu, 2023).

The second group is analytical. Standardized damage correlated limits for large slow slew bearings require industry data pooling across operators and bearing manufacturers, and machine learning classification of FTIR and ferrographic signatures requires training libraries that no single operator can assemble alone. The interpretability requirement is significant: Early failure prediction models for distributed assets are adopted in practice only when their outputs can be explained to the engineers who must act on them (Komi and Adamolekun, 2021), and forecasting research more generally confirms that predictive performance follows from the physical fidelity of the inputs rather than from model complexity (Komi, 2021). Automated classification of high volume condition imagery in adjacent inspection domains indicates both the feasibility and the data appetite of such approaches (Dagodzo, Ahiaeke Patrick, and Aliliele, 2022), and anomaly detection methods for operational time series offer a complementary route where the diagnostic question is deviation from an established pattern rather than classification of a known state (Atakpa and Fobellah, 2023).

The third group concerns integration and architecture. Tiered digital twin representations of export mechanical assets should ingest periodic grease results alongside geometric and operational data without demanding instrumentation density that offshore facilities cannot support (Komi and Adeniji, 2023), and the allocation of decision authority between offshore edge processing and onshore analysis remains an open design question of the kind examined in distributed control architecture research (Komi and Adamolekun, 2022). Degradation modeling under adverse ambient conditions in other asset classes suggests that environment specific rather than generic degradation models will be required (Komi and Ganiu, 2022), and co-optimization approaches that balance technical performance against operating constraints indicate how such models are made usable in resource constrained settings (Komi and Adeniji, 2020).

The fourth group is inspection and automation integration. Formal P-F interval characterization for SPM and turret bearing failure modes would put sampling interval selection on a firmer statistical footing. Combining grease sampling with remote and geospatially referenced inspection would allow condition evidence from multiple sources to be aggregated against a single asset record (Dagodzo and Ahiaeke Patrick, 2020; Dagodzo and Ahiaeke Patrick, 2023a; Dagodzo, 2018a; Dagodzo, 2018b), and change detection methods developed for repeated corridor observation offer the analytical pattern for repeated sampling at fixed points (Dagodzo and Ahiaeke Patrick, 2022). Longer term, as terminals adopt modified power systems and higher renewable penetration, the electrical and thermal duty on export equipment will change, and the monitoring program should anticipate rather than follow those changes (Adenuga, 2022; Adenuga, 2023). Industry joint projects, following the pattern of OREDA style data sharing, are the natural vehicle for all four groups.

8. Conclusion

Offshore crude export terminals concentrate enormous commercial exposure in a small set of grease lubricated mechanical assets that conventional condition monitoring cannot see. As of 2023, grease analysis had matured, through the ASTM D7718 sampling practice, the ASTM D7918 small sample method family, supporting spectroscopic, ferrographic, and physical test methods, and accumulated industry experience with slow rotating bearings, into a practical, standardized, and economical predictive maintenance technology precisely suited to this asset class. The concept developed in this paper assigns every greased export asset fixed sampling points, criticality based intervals, a defined laboratory slate, statistically trended per point limits, and staged alarm and decision logic integrated with the terminal reliability program, its digital architecture, its safety management system, and its materials supply chain.

Its implementation cost is trivial against the deferment value of a single avoided export interruption, and its strategic value lies in converting the least observable, highest consequence failure modes on the export path, main bearing degradation, swivel seal failure, and contamination driven wear, into slowly developing, measurable, and manageable conditions. The wide body of literature reviewed here reinforces the direction of travel. Adjacent asset domains have consistently found that dispersed, hard to reach, high consequence equipment becomes manageable once a modest but genuinely diagnostic measurement is taken regularly and tied to a persistent asset record (Komi and Adeniji, 2023; Adelanwa, Basnet, and Anene, 2023a; Okonkwo, Mayo, and Okeke, 2023); industrial safety practice has established that rare severe outcomes are managed through frequent minor observations (Arumosoye and Obriki, 2019; Obriki and Arumosoye, 2023); and supply chain research has established that early condition signals are what convert maintenance from a cost of failure into a planned commitment (Okonkwo, Agbabiaka, Ogunwole, Mayo, and Okeke, 2021; Okonkwo, Ogunwole, and Okeke, 2018b). For operators of SPM terminals, FPSOs, and crude loading jetties, the conclusion is direct: Grease analysis should be adopted as the primary condition monitoring technology for grease lubricated export assets, with vibration, acoustic emission, geometric measurement, and inspection arranged around it as complements rather than the reverse.

9. References

1. Abioye RF, Okojie JS, Filani OM, Ike PN, Idu JOO, Nnabueze SB, *et al*. Automated ESG reporting in energy projects using blockchain-driven smart compliance management systems. International Journal of Multidisciplinary Evolutionary Research. 2023;

4(2):120-129. Doi: https://doi.org/10.54660/IJMER.2023.4.2.120-129
2. Adebayo A, Adegbite MP, Ahmed MO. Adversarial machine learning in critical infrastructure: A conceptual framework for threat modeling AI enabled OT systems. World Journal of Innovation and Modern Technology. 2022; 6(1):184-234. Doi: https://doi.org/10.56201/wjimt.v6.no1.2022.pg184.234
3. Adebayo A, Adegbite MP, Ahmed MO. AI augmented threat detection in industrial control systems: A systematic review of machine learning approaches for ICS anomaly detection. International Journal of Engineering and Modern Technology. 2023; 9(3):287-340. Doi: https://doi.org/10.56201/ijcsmt.v9.no3.2023.pg287.340
4. Adegbite MP, Adebayo A, Ahmed MO. Securing operational technology networks in electric utilities: A systematic review of NERC CIP compliance and architectural threat mitigation. International Journal of Engineering and Modern Technology. 2020; 6(3):103-146. Doi: https://doi.org/10.56201/ijemt.vol.6.no3.2020.pg103.146
5. Adegbite MP, Adebayo A, Ahmed MO. A security architecture model for IT and OT convergence in regulated energy networks: Design principles and governance alignment. International Journal of Computer Science and Mathematical Theory. 2022; 8(2):81-132. Doi: https://doi.org/10.56201/ijcsmt.v8.no2.2022.pg81.132
6. Adegbite MP, Adebayo A, Ahmed MO. ICS and SCADA threat detection architectures in energy sector networks: A systematic review of SIEM, NDR, and anomaly detection approaches. World Journal of Innovation and Modern Technology. 2023; 7(2):121-182. Doi: https://doi.org/10.56201/wjimt.v7.no2.2023.pg121.182
7. Adelanwa A, Basnet A, Anene UN. Data driven digital transformation models for lifecycle performance management in infrastructure delivery. International Journal of Advanced Multidisciplinary Research and Studies. 2023a; 3(6):2646-2662. Doi: https://doi.org/10.62225/2583049X.2023.3.6.5968
8. Adenuga OM. Smart grid architectures and energy distribution for high renewable penetration: A comprehensive review of technologies, operations, and deployment pathways. International Journal of Engineering and Modern Technology. 2022; 8(5):125-155. Doi: https://doi.org/10.56201/ijemt.v8.no5.2022.pg125.155
9. Adenuga OM. Power electronics and energy efficiency in modern power systems: A comprehensive review of devices, converter topologies, and system-level practice. International Journal of Engineering and Modern Technology. 2023; 9(3):287-312. Doi: https://doi.org/10.56201/ijcsmt.v9.no3.2023.pg287.312
10. Adeyelu OO. A predictive compliance monitoring framework for detecting systemic safety risks through aviation consumer complaint data. Iconic Research and Engineering Journals. 2018; 1(8):250-276. Doi: https://doi.org/10.64388/IREV1I8-1718478
11. Adeyelu OO. An adaptive safety management system implementation model for aerodromes in developing economy contexts. Iconic Research and Engineering Journals. 2019; 3(4):628-654. Doi: https://doi.org/10.64388/IREV3I4-1718479
12. Adeyelu OO. An artificial intelligence-driven conceptual model for wildlife strike risk quantification and aircraft airworthiness impact assessment at high-traffic African airports. Iconic Research and Engineering Journals. 2020; 4(1):339-368. Doi: https://doi.org/10.64388/IREV4I1-1718482
13. Adeyelu OO. A framework for managing encroachments and unauthorized structures around airport boundaries: Regulatory evidence, enforcement, and corrective action protocols for Nigerian civil aviation. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):954-972. Doi: https://doi.org/10.54660/.IJMRGE.2021.2.6.954-972
14. Adeyelu OO. A regulatory evidence framework for assessing unauthorized structure violations within protected airport obstacle limitation surfaces. International Journal of Scientific Research in Civil Engineering. 2022; 6(6):248-283. Doi: https://doi.org/10.32628/IJSRCE229673
15. Adeyelu OO. A risk-tiered oversight model for unmanned aircraft operations in shared controlled airspace over Nigerian airports. International Journal of Scientific Research in Civil Engineering. 2023; 7(4):147-184. Doi: https://doi.org/10.32628/IJSRCE237419
16. Adeyelu OO, Dagodzo D. A comparative benchmarking model for aerodrome certification compliance across developing economy civil aviation authorities. International Journal of Multidisciplinary Research and Growth Evaluation. 2022; 3(6):1016-1035. Doi: https://doi.org/10.54660/.IJMRGE.2022.3.6.1016-1035
17. Agbabiaka J, Okonkwo CS, Ogunwole O, Mayo W, Okeke OT. Supply chain risk management model for EPC and gas processing projects. Iconic Research and Engineering Journals. 2019; 3(2):968-980. Doi: https://doi.org/10.64388/IREV3I2-1713124
18. Ahiaeke Patrick MC, Okonkwo CS, Mayo W, Okeke OT. A GIS enabled framework for modern ERP procurement processes. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):499-508. Doi: https://doi.org/10.54660/IJMRGE.2020.1.5.499-508
19. Ahiaeke Patrick MC, Okonkwo CS, Mayo W, Okeke OT. Model for data driven vendor evaluation and bid selection using geospatial intelligence. Shodhshauryam, International Scientific Refereed Research Journal. 2021; 4(4):426-443. Doi: https://doi.org/10.32628/SHISRRJ214461
20. Ahmed MO, Adegbite MP, Adebayo A. Zero trust architecture for operational technology in North American critical infrastructure: A framework for implementation and resilience optimization. International Journal of Engineering and Modern Technology. 2021; 7(1):66-113. Doi: https://doi.org/10.56201/ijemt.vol.7.no1.2021.pg66.113
21. Aifuwa SE, Oshoba TO, Ogbuefi E, Ike PN, Nnabueze SB, Olatunde-Thorpe J. Predictive analytics models enhancing supply chain demand forecasting accuracy and reducing inventory management inefficiencies. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(3):171-181. Doi:

https://doi.org/10.54660/.IJMRGE.2020.1.3.171-181
22. Akin-Oluyomi OT, Atima ME, Akinleye OK. Green procurement strategies for balancing cost efficiency with long-term environmental responsibility. International Journal of Advanced Multidisciplinary Research and Studies. 2023a; 3(6):2183-2193.
23. Akin-Oluyomi OT, Atima ME, Akinleye OK. Regulatory compliance and supplier risk assessment frameworks in international pharmaceutical procurement. International Journal of Advanced Multidisciplinary Research and Studies. 2023b; 3(6):2194-2204.
24. Akin-Oluyomi OT, Atima ME, Akinleye OK, Okoruwa PO. Predictive analytics approaches for improving demand forecasting accuracy in e-commerce procurement systems. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2173-2182.
25. Akinleye OK, Adeyoyin O. Process automation framework for enhancing procurement efficiency and transparency. Shodhshauryam, International Scientific Refereed Research Journal. 2021; 4(4):356-387.
26. Akinleye OK, Adeyoyin O. A negotiation optimization model for reducing procurement costs in manufacturing firms. Shodhshauryam, International Scientific Refereed Research Journal. 2022a; 5(5):398-435. Doi: https://doi.org/10.32628/SHISRRJ225891
27. Akinleye OK, Adeyoyin O. Supplier relationship management framework for achieving strategic procurement objectives. Gyanshauryam, International Scientific Refereed Research Journal. 2022b; 5(4):565-598. Doi: https://doi.org/10.32628/GISRRJ225430
28. Akinleye OK, Okoruwa PO, Babatope OM, Akokodaripon DA. Leveraging big data and business intelligence for optimization of manufacturing sector procurement. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2164-2172.
29. Akomolafe O, Agu MU. A conceptual model for enhancing internal audit quality through technology-enabled risk assessment frameworks. Iconic Research and Engineering Journals. 2018; 1(9):458-475.
30. Aliliele C, Mbonu IS, Iwuanyanwu U. A conceptual framework for continuous cloud misconfiguration monitoring and enterprise risk mitigation strategies. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023a; 9(10):373-394. Doi: https://doi.org/10.32628/CSEIT2361071
31. Aliliele C, Mbonu IS, Iwuanyanwu U. A review of API governance and risk prioritization frameworks in modern financial institutions. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023b; 9(10):395-433. Doi: https://doi.org/10.32628/CSEIT2361072
32. Amayo EB. Multi algorithm of loss objective function of a single phase induction motor. International Journal of Development Research. 2017; 7(5):12805-12810.
33. Amayo EB, Popoola TT. Multi algorithm of weight objective function of a single phase induction motor. International Journal of Trend in Research and Development. 2017a; 4(2):184-188.
34. Amayo EB, Owulade OA, Isi LR. Optimizing project governance in multinational infrastructure projects: Insights from General Electric's global operations. International Journal of Multidisciplinary Research and Growth Evaluation. 2023a; 4(1):975-983. Doi: https://doi.org/10.54660/.IJMRGE.2023.4.1.975-983
35. Amayo EB, Owulade OA, Isi LR. Risk management strategies and compliance frameworks in healthcare infrastructure projects: Case studies from West Africa. International Journal of Management and Organizational Research. 2023b; 2(1):161-168. Doi: https://doi.org/10.54660/IJMOR.2023.2.1.161-168
36. Amayo EB, Ubeku E, Oshevire P. Multi algorithm of a single objective function of a single phase induction motor. Journal of Multidisciplinary Engineering Science and Technology. 2015; 2(12):3400-3403.
37. Ambali KB, Eyetsemitan RA, Oyeleye AO, Fadayomi O. Lean Six Sigma for small enterprises: A systematic review and Lite-DMAIC adaptation framework for resource-constrained organizations. Iconic Research and Engineering Journals. 2021; 5(5):562-583. Doi: https://doi.org/10.64388/IREV5I5-1716957
38. Aminu-Ibrahim AY, Ogbete JC, Ambali KB. Developing sustainable diagnostic laboratory infrastructure models for emerging and resource constrained health systems. Iconic Research and Engineering Journals. 2018; 1(8):118-132. Doi: https://doi.org/10.64388/IREV1I8-1713586
39. Aminu-Ibrahim AY, Ogbete JC, Ambali KB. Capital project delivery models for high risk healthcare infrastructure in developing national health systems. Iconic Research and Engineering Journals. 2019; 2(10):626-649. Doi: https://doi.org/10.64388/IREV2I10-1713588
40. Arumosoye OM, Obriki OD. Development of an integrated heat stress risk conceptual model for industrial operations in extreme environments. Iconic Research and Engineering Journals. 2018; 1(12):141-160. Doi: https://doi.org/10.64388/IREV1I12-1714415
41. Arumosoye OM, Obriki OD. Systematic review of near-miss and hazard observation data utilization in industrial safety management. Iconic Research and Engineering Journals. 2019; 3(2):981-999. Doi: https://doi.org/10.64388/IREV3I2-1714417
42. Arumosoye OM, Obriki OD. A governance-oriented conceptual model for contractor safety performance in multi-contract industrial projects. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):728-740. Doi: https://doi.org/10.54660/.IJMRGE.2020.1.5.728-740
43. Arumosoye OM, Obriki OD. Organizational learning-based conceptual maturity model for continuous safety performance improvement. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(1):970-980. Doi: https://doi.org/10.54660/.IJMRGE.2021.2.1.970-980
44. Arumosoye OM, Obriki OD. Conceptual risk pathway model for lifting and rigging operations in heavy industrial construction. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(5):346-369. Doi: https://doi.org/10.32628/GISRRJ2256237
45. Arumosoye OM, Obriki OD. Conceptual model for emergency response readiness and capability in energy and process facilities. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023; 9(3):897-917. Doi:

https://doi.org/10.32628/CSEIT25112791
46. Asiedu W, Quainoo R. How far can energy harvesting take us? A systematic review of radio frequency strategies for energy autonomous sensing. Shodhshauryam, International Scientific Refereed Research Journal. 2023a; 6(1):448-466.
47. Asiedu W, Quainoo R. Toward maintenance free wireless infrastructure: Simulating performance and reliability in large scale intermittently powered IoT networks. Gyanshauryam, International Scientific Refereed Research Journal. 2023b; 6(1):489-510.
48. ASTM International. ASTM D1403, Standard Test Methods for Cone Penetration of Lubricating Grease Using One-Quarter and One-Half Scale Cone Equipment. West Conshohocken, PA: ASTM International.
49. ASTM International. ASTM D5185, Standard Test Method for Multielement Determination of Used and Unused Lubricating Oils and Base Oils by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES). West Conshohocken, PA: ASTM International.
50. ASTM International. ASTM D6304, Standard Test Method for Determination of Water in Petroleum Products, Lubricating Oils, and Additives by Coulometric Karl Fischer Titration. West Conshohocken, PA: ASTM International.
51. ASTM International. ASTM D6971, Standard Test Method for Determination of Hindered Phenolic and Aromatic Amine Antioxidant Content Using Linear Sweep Voltammetry. West Conshohocken, PA: ASTM International.
52. ASTM International. ASTM D7684, Standard Guide for Microscopic Characterization of Particles from In-Service Lubricants. West Conshohocken, PA: ASTM International.
53. ASTM International. ASTM D7718, Standard Practice for Obtaining In-Service Samples of Lubricating Grease. West Conshohocken, PA: ASTM International.
54. ASTM International. ASTM D7918, Standard Test Method for Measurement of Flow Properties and Evaluation of Wear, Contaminants, and Oxidative Properties of Lubricating Grease by Die Extrusion Method and Preparation. West Conshohocken, PA: ASTM International.
55. ASTM International. ASTM E2412, Standard Practice for Condition Monitoring of In-Service Lubricants by Trend Analysis Using Fourier Transform Infrared (FT-IR) Spectrometry. West Conshohocken, PA: ASTM International.
56. Atakpa MI, Fobellah AN. Anomaly detection in financial time-series data: A conceptual model for healthcare and banking applications. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023; 9(2):967-997. Doi: https://doi.org/10.32628/CSEIT2342441
57. Atta S, Adjaklo E, Asomani E, Adenuga OM. Advances in welding inspection standards and quality assurance practices in large-scale power generation projects. International Journal of Engineering and Modern Technology. 2022; 8(5):101-124. Doi: https://doi.org/10.56201/ijemt.v8.no5.2022.pg101.124
58. Atta S, Asomani E, Adenuga OM. A systematic review of green corrosion inhibitors from agricultural extracts for mild steel protection in acidic and alkaline media. International Journal of Engineering and Modern Technology. 2018; 4(1):64-97. Doi: https://doi.org/10.56201/ijemt.vol.4.no1.2018.pg64.97
59. Atta S, Tofah P, Adenuga OM. Advances in non-destructive testing methods for weld integrity evaluation in high-capacity power infrastructure. International Journal of Engineering and Modern Technology. 2021; 7(1):20-47. Doi: https://doi.org/10.56201/ijemt.vol.7.no1.2021.pg20.47
60. Atta S, Tofah P, Kankam MA, Adenuga OM. A critical review of NDT-based integrity management and corrosion risk assessment strategies for refinery process equipment. International Journal of Engineering and Modern Technology. 2020; 6(2):19-46. Doi: https://doi.org/10.56201/ijemt.vol.6.no2.2020.pg19.46
61. Babatope OM, Akokodaripon DA, Akinleye OK, Okoruwa PO. The role of data visualization in enhancing strategic procurement decision-making effectiveness. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2205-2212.
62. Bello KA, Adama A, Tawose OM, Bolaji BO. Development and performance evaluation of a poultry bird de-feathering machine. FUOYE Journal of Engineering and Technology. 2022; 7(4).
63. Bello KA, Azeez TM, Tawose OM, Odesanya KO, Odumosu OA, Oyelaran OA. Investigating the influence of rubber seed oil and used cooking oil on diesel. E3S Web of Conferences, 430, Article 01217, 2023. Doi: https://doi.org/10.1051/e3sconf/202343001217
64. Bello KA, Tawose OM, Adama A, Bolaji BO. Factor analysis of poultry birds de-feathering machines. FUOYE Journal of Engineering and Technology. 2022; 7(3). Doi: https://doi.org/10.46792/fuoyejet.v7i3.829
65. Dagodzo D. A conceptual framework for UAV integration into national power grid inspection programs. Iconic Research and Engineering Journals. 2018a; 2(5):391-412. Doi: https://doi.org/10.64388/IREV2I5-1716082
66. Dagodzo D. A review of UAV applications in electrical transmission line inspection: Methods, technologies, and challenges. Iconic Research and Engineering Journals. 2018b; 2(6):234-254. Doi: https://doi.org/10.64388/IREV2I6-1716083
67. Dagodzo D, Ahiaeke Patrick MC. UAV-based pipeline and corridor monitoring: A review of current practices and emerging technologies. Iconic Research and Engineering Journals. 2020; 3(10):574-597. Doi: https://doi.org/10.64388/IREV3I10-1716084
68. Dagodzo D, Ahiaeke Patrick MC. A review of GIS applications in utility asset management and infrastructure planning. Iconic Research and Engineering Journals. 2021a; 5(3):468-492. Doi: https://doi.org/10.64388/IREV5I3-1716085
69. Dagodzo D, Ahiaeke Patrick MC. An integrated framework for UAV, LiDAR, and GIS in infrastructure corridor management. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2021b; 7(5):497-524. Doi: https://doi.org/10.32628/CSEIT217566
70. Dagodzo D, Ahiaeke Patrick MC. A review of right-of-way encroachment detection methods using geospatial

technologies. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2022; 8(1):638-667. Doi: https://doi.org/10.32628/CSEIT2281226
71. Dagodzo D, Ahiaeke Patrick MC. A framework for integrating drone operations into enterprise GIS systems for utility companies. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023a; 9(4):924-957. Doi: https://doi.org/10.32628/CSEIT23564536
72. Dagodzo D, Ahiaeke Patrick MC, Aliliele C. AI and deep learning for vegetation classification in power corridor management: A review. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2022; 8(1):668-698. Doi: https://doi.org/10.32628/CSEIT2281227 Lean Operations and Small Business Process Improvement
73. Dosunmu AA, Ogundele PO. Security audit and enterprise risk assessment frameworks for resilient information systems. Iconic Research and Engineering Journals. 2019; 3(5):434-447. Doi: https://doi.org/10.64388/IREV3I5-1713225
74. Dosunmu AA, Ogundele PO. Intrusion detection and prevention models for enhancing organizational cyber defense effectiveness. Iconic Research and Engineering Journals. 2020; 4(6):310-324. Doi: https://doi.org/10.64388/IREV4I6-1713226
75. Edivri J, Oteri O. Predictive capacity planning and resource utilization forecasting models for multi-program and multi-stakeholder IT portfolios. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2022; 8(4):826-845.
76. Efobi OZ, Akinleye OK, Fasawe O. Conceptual framework for sustainable procurement practices in local manufacturing enterprises in Africa. Gyanshauryam, International Scientific Refereed Research Journal. 2022a; 5(6):248-266.
77. Efobi OZ, Akinleye OK, Fasawe O. Conceptual model for data-driven lean supply chain optimization in manufacturing and retail operations. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2022b; 8(2):703-734. Doi: https://doi.org/10.32628/CSEIT2541335
78. Efobi OZ, Akinleye OK, Fasawe O. Conceptual framework for developing a resilience index for post-pandemic supply chains. Shodhshauryam, International Scientific Refereed Research Journal. 2023; 6(2):421-432.
79. 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 Research and Engineering Journals. 2020; 4(4):418-441. Doi: https://doi.org/10.64388/IREV4I4-1716955
80. Eyetsemitan RA, Ambali KB, Oyeleye AO, Fadayomi O. Translating tax and regulatory requirements into SME compliance workflows: A conceptual framework for implementing IAS 12, VAT, PAYE, and withholding tax. Iconic Research and Engineering Journals. 2021; 4(11):621-641. Doi: https://doi.org/10.64388/IREV4I11-1716956
81. Eyetsemitan RA, Ambali KB, Oyeleye AO, Fadayomi O. Change management in small business digital transformation: A systematic review and lean change adoption framework. Gyanshauryam, International Scientific Refereed Research Journal. 2023a; 6(6):521-550. Doi: https://doi.org/10.32628/GISRRJ236648
82. Eyetsemitan RA, Ambali KB, Oyeleye AO, Fadayomi O. User acceptance testing in small business technology deployment: A structured validation framework for lean operational environments. International Journal of Multidisciplinary Research and Growth Evaluation. 2023b; 4(6):1512-1531. Doi: https://doi.org/10.54660/IJMRGE.2023.4.6.1512-1531
83. Eyetsemitan RA, Oyeleye AO, Ambali KB, Fadayomi O. Standard operating procedures as strategic assets in small business operations: A systematic review and implementation framework. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(2):438-465. Doi: https://doi.org/10.32628/GISRRJ225356
84. Eze FI, Anene UN, Akinleye OK. Creation of a drug shortage early warning and regulatory response model for essential medicines in global health systems. Research Journal of Pure Science and Technology. 2022a; 5(1):57-95. Doi: https://doi.org/10.56201/rjpst.v5.no1.2022.pg57.95
85. Falegan OC, Aniebonam SO. Conceptual framework for lifecycle risk assessment in offshore produced water management. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(5):322-345.
86. Falegan OC, Aniebonam SO. Integrated physicochemical and bio-based treatment strategies for produced water in arid environments: A review. Gyanshauryam, International Scientific Refereed Research Journal. 2023; 6(1):425-443.
87. Filani OM, Nnabueze SB, Ike PN, Wedraogo L. Real-time risk assessment dashboards using machine learning in hospital supply chain management systems. International Journal of Multidisciplinary Evolutionary Research. 2022; 3(1):65-76. Doi: https://doi.org/10.54660/IJMER.2022.3.1.65-76
88. Ike PN, Ogbuefi E, Nnabueze SB, Olatunde-Thorpe J, Aifuwa SE, Oshoba TO, *et al*. Supplier relationship management strategies fostering innovation, collaboration, and resilience in global supply chain ecosystems. International Journal of Multidisciplinary Evolutionary Research. 2021; 2(2):52-62. Doi: https://doi.org/10.54660/IJMER.2021.2.2.52-62
89. Ike PN, Ogbuefi E, Nnabueze SB, Olatunde-Thorpe J, Aifuwa SE, Oshoba TO, *et al*. Lean supply chain practices improving operational efficiency, reducing waste, and enhancing organizational competitiveness globally. Journal of Frontiers in Multidisciplinary Research. 2022; 3(2):182-192. Doi: https://doi.org/10.54660/.IJFMR.2022.3.2.182-192
90. International Organization for Standardization. ISO 14224, Petroleum, Petrochemical and Natural Gas Industries: Collection and Exchange of Reliability and Maintenance Data for Equipment. Geneva: ISO, 2016.
91. International Organization for Standardization. ISO 17359, Condition Monitoring and Diagnostics of Machines: General Guidelines. Geneva: ISO.
92. International Organization for Standardization. ISO

18436, Condition Monitoring and Diagnostics of Machines: Requirements for Qualification and Assessment of Personnel. Geneva: ISO.
93. Jimoh HO, Abolle-Okoyeagu CJ, Ahmed MO, Lawal NO. Advancing security in IoT-driven critical infrastructure: A focus on smart transportation system. American Journal of Engineering Research. 2023; 12(12):33-46.
94. Komi NM. Hybrid deep learning for wind power forecasting: From grid stability to market equity for small generators. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):989-1014. Doi: https://doi.org/10.54660/.IJMRGE.2021.2.6.989-1014
95. Komi NM, Adamolekun A. Interpretable machine learning for early failure prediction in distributed renewable energy assets. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):1015-1038. Doi: https://doi.org/10.54660/.IJMRGE.2021.2.6.1015-1038
96. Komi NM, Adamolekun A. Hierarchical, decentralized, or hybrid? A systematic review of control architectures for distributed energy resources. International Journal of Engineering and Modern Technology. 2022; 8(5):141-195. Doi: https://doi.org/10.56201/ijemt.v8.no5.2022.pg141.195
97. Komi NM, Adeniji IO. Co-optimizing technical performance and community affordability in smart solar microgrids for underserved regions. International Journal of Engineering and Modern Technology. 2020; 6(3):173-212. Doi: https://doi.org/10.56201/ijemt.vol.6.no3.2020.pg173.212
98. Komi NM, Adeniji IO. A tiered digital twin that brings predictive diagnostics to resource-constrained renewable energy sites. International Journal of Engineering and Modern Technology. 2023; 9(3):287-347. Doi: https://doi.org/10.56201/ijemt.v9.no3.2023.pg287.347
99. Komi NM, Ganiu OS. Grid-connected battery storage in hot and weak-grid regions: Advances, degradation challenges, and lifecycle equity. International Journal of Multidisciplinary Research and Growth Evaluation. 2022; 3(6):1072-1095. Doi: https://doi.org/10.54660/.IJMRGE.2022.3.6.1072-1095
100. Komi NM, Ganiu OS. Edge intelligence for resilient microgrid control: Advances, energy sovereignty, and open challenges. Gyanshauryam, International Scientific Refereed Research Journal. 2023; 6(3):525-586. Doi: https://doi.org/10.32628/GISRRJ236339
101. Ladapo OO, Dosunmu AA, Jooda D, Abolaji TO. An IT service management literature review: Challenges, benefits, opportunities, and implementation practices. International Journal of Advanced Multidisciplinary Research and Studies. 2023b; 3(6):2875-2889. Doi: https://doi.org/10.62225/2583049X.2023.3.6.6205
102. Ladapo OO, Jooda D, Dosunmu AA, Abolaji TO. A comprehensive survey on ServiceNow for IT service management. International Journal of Multidisciplinary Research and Growth Evaluation. 2023a; 4(6):1532-1545. Doi: https://doi.org/10.54660/.IJMRGE.2023.4.6.1532-1545
103. Lawal OA, Oduleye TE. A conceptual model for financial analytics driven enterprise value creation in technology firms. Iconic Research and Engineering Journals. 2018a; 2(2).
104. Lawal OA, Oduleye TE. A conceptual decision model for capital allocation using financial analytics. Gyanshauryam, International Scientific Refereed Research Journal. 2021a; 4(2):269-295.
105. Lugt PM. Grease Lubrication in Rolling Bearings. Chichester: John Wiley and Sons, 2013.
106. Mbonu IS, Aliliele C, Iwuanyanwu U, Uzoka E. A review of identity and access management integration strategies in hybrid and multi cloud environments. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):795-810. Doi: https://doi.org/10.54660/.IJMRGE.2020.1.5.795-810
107. Mbonu IS, Aliliele C, Iwuanyanwu U, Uzoka E. A conceptual framework for risk based business intelligence architecture in financial technology platforms. International Journal of Multidisciplinary Research and Growth Evaluation. 2021a; 2(6):731-746. Doi: https://doi.org/10.54660/.IJMRGE.2021.2.6.731-746
108. Mbonu IS, Aliliele C, Iwuanyanwu U, Uzoka E. A conceptual framework for AI enabled IT general controls and SOX audit automation processes. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(5):384-414. Doi: https://doi.org/10.32628/GISRRJ2256239
109. Mbonu IS, Iwuanyanwu U, Aliliele C, Uzoka E. A conceptual framework for agile supply chain digital transformation with embedded IT risk and ISO compliance controls. Iconic Research and Engineering Journals. 2020a; 3(11):566-593. Doi: https://doi.org/10.64388/IREV3I11-1714916
110. Mbonu IS, Iwuanyanwu U, Uzoka E, Oluoha OM. Advances in enterprise log analytics and automated incident response architectures using Python and SIEM platforms. Iconic Research and Engineering Journals. 2019; 3(2):1000-1019. Doi: https://doi.org/10.64388/IREV3I2-1714915
111. Medon JJ, Oduleye TE. A comprehensive financial reporting model for strengthening compliance and organizational accountability systems. International Journal of Multidisciplinary Research and Growth Evaluation. 2022; 3(6):768-777.
112. Nnabueze SB, Ike PN, Olatunde-Thorpe J, Aifuwa SE, Oshoba TO, Ogbuefi E, *et al*. End-to-end visibility frameworks improving transparency, compliance, and traceability across complex global supply chain operations. International Journal of Multidisciplinary Futuristic Development. 2021; 2(2):50-60. Doi: https://doi.org/10.54660/IJMFD.2021.2.2.50-60
113. Obogo SF, Arumosoye OM, Obriki OD. Advances in internal QHSE audit systems for industrial engineering operations. Iconic Research and Engineering Journals. 2020a; 4(4):399-417. Doi: https://doi.org/10.64388/IREV4I4-1715499
114. Obogo SF, Arumosoye OM, Obriki OD. Conceptual risk management model for heavy lifting and crane installation engineering operations. Shodhshauryam, International Scientific Refereed Research Journal. 2020b; 3(4):122-144. Doi: https://doi.org/10.32628/SHISRRJ214441
115. Obogo SF, Arumosoye OM, Obriki OD. Critical review of occupational safety management systems in oil and

gas maintenance projects. Shodhshauryam, International Scientific Refereed Research Journal. 2020c; 3(4):145-166. Doi: https://doi.org/10.32628/SHISRRJ214442
116. Obogo SF, Arumosoye OM, Obriki OD. Advances in proactive hazard recognition and near miss reporting systems. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):835-846. Doi: https://doi.org/10.54660/IJMRGE.2021.2.6.835-846
117. Obogo SF, Nwafor MI, Ozobu CO. Conceptual leadership model for safety culture development in construction and engineering projects. International Journal of Scientific Research in Civil Engineering. 2023; 7(6):121-153. Doi: https://doi.org/10.32628/IJSRCE237554
118. Obogo SF, Obriki OD, Arumosoye OM. Conceptual model for incident prevention in industrial maintenance engineering environments. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):847-858. Doi: https://doi.org/10.54660/IJMRGE.2021.2.6.847-858
119. Obogo SF, Obriki OD, Arumosoye OM. Conceptual safety governance model for large commercial facility operations. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(6):383-410. Doi: https://doi.org/10.32628/GISRRJ225639
120. Obogo SF, Uduokhai DO, Ozobu CO. Systematic review of hazard identification and risk control practices in urban construction projects. Iconic Research and Engineering Journals. 2019; 2(12):666-681. Doi: https://doi.org/10.64388/IREV2I12-1715496
121. Obogo SF, Uduokhai DO, Ozobu CO. Review of contractor safety compliance systems in infrastructure engineering projects. International Journal of Scientific Research in Civil Engineering. 2021; 5(4):76-100. Doi: https://doi.org/10.32628/IJSRCE215412
122. Obriki OD, Arumosoye OM. Conceptual modeling of data-driven occupational safety risk control in large-scale energy infrastructure projects. Iconic Research and Engineering Journals. 2018; 1(7):169-189. Doi: https://doi.org/10.64388/IREV1I7-1714414
123. Obriki OD, Arumosoye OM. A conceptual framework linking management safety walkthrough frequency and coverage to safety culture outcomes in mega projects. Iconic Research and Engineering Journals. 2019; 2(8):355-374. Doi: https://doi.org/10.64388/IREV2I8-1714416
124. Obriki OD, Arumosoye OM. Conceptual framework for human error causation in high-risk construction and industrial activities. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):715-727. Doi: https://doi.org/10.54660/.IJMRGE.2020.1.5.715-727
125. Obriki OD, Arumosoye OM. Conceptual model for institutionalizing life-preserving safety practices across project-based organizations. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(1):961-969. Doi: https://doi.org/10.54660/.IJMRGE.2021.2.1.961-969
126. Obriki OD, Arumosoye OM. Conceptual framework explaining recurrence mechanisms of unsafe behaviors in high-hazard worksites. Shodhshauryam, International Scientific Refereed Research Journal. 2022; 5(3):380-402. Doi: https://doi.org/10.32628/SHISRRJ225489
127. Obriki OD, Arumosoye OM. Conceptual framework for proactive hazard identification using digital safety data streams. Gyanshauryam, International Scientific Refereed Research Journal. 2023; 6(3):457-481. Doi: https://doi.org/10.32628/GISRRJ236336
128. Obriki OD, Arumosoye OM, Obogo SF. Advances in continuous hazard monitoring systems for workplace safety. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2742-2759. Doi: https://doi.org/10.62225/2583049X.2023.3.6.6075
129. Obriki OD, Obogo SF, Arumosoye OM. Advances in workforce safety training models for operational risk reduction. Gyanshauryam, International Scientific Refereed Research Journal. 2022a; 5(6):349-382. Doi: https://doi.org/10.32628/GISRRJ225638
130. Obriki OD, Obogo SF, Arumosoye OM. Review of emergency preparedness and evacuation systems in high density commercial buildings. Gyanshauryam, International Scientific Refereed Research Journal. 2022b; 5(6):411-438. Doi: https://doi.org/10.32628/GISRRJ225640
131. Obriki OD, Obogo SF, Arumosoye OM. Review of behavioral safety programs for risk reduction in large workforces. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2760-2775. Doi: https://doi.org/10.62225/2583049X.2023.3.6.6076
Cybersecurity, Data Governance, and IT Risk
132. Oduleye TE, Medon JJ. A predictive model for optimizing cash flow and working capital management in corporations. Gyanshauryam, International Scientific Refereed Research Journal. 2023a; 6(5):739-754. Doi: https://doi.org/10.32628/GISRRJ236537
133. Oduleye TE, Medon JJ. A quantitative model for measuring the strategic impact of financial analysis on enterprise growth. International Journal of Advanced Multidisciplinary Research and Studies. 2023b; 3(1):1663-1672. Doi: https://doi.org/10.62225/2583049X.2023.3.1.5334
134. Ogbete JC, Aminu-Ibrahim AY, Ambali KB. Sustainable materials selection and energy efficiency strategies for modern medical laboratory facilities. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):674-690. Doi: https://doi.org/10.54660/IJMRGE.2020.1.5.674-690
135. Ogbete JC, Aminu-Ibrahim AY, Ambali KB. Risk managed construction strategies for complex and highly regulated healthcare facility developments. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2021; 7(5):362-392. Doi: https://doi.org/10.32628/CSEIT217561
136. Ogbete JC, Aminu-Ibrahim AY, Ambali KB. Lifecycle performance evaluation of purpose built diagnostic laboratories supporting long term healthcare delivery. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2605-2621. Doi: https://doi.org/10.62225/2583049X.2023.3.6.5698
137. Ogbole JI, Okoruwa PO, Fadayomi O, Abolaji TO, Edivri J, Akeju B. Conceptual model for identity-

centric zero trust architecture in enterprise security governance. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2021; 7(5):393-415. Doi: https://doi.org/10.32628/IJSRCSEIT217562
138. Ogunwole O, Okonkwo CS, Agbabiaka J, Mayo W, Okeke OT. Supply chain resilience framework for critical infrastructure and gas processing plants. Shodhshauryam, International Scientific Refereed Research Journal. 2021; 4(4):444-461. Doi: https://doi.org/10.32628/SHISRRJ214462
139. Oil Companies International Marine Forum (OCIMF). Single Point Mooring Maintenance and Operations Guide (SMOG). London: OCIMF.
140. Okojie JS, Abioye RF. Reconciling chemical safety with circular-economy targets: A decision framework for post-consumer recycled polymers in consumer-goods packaging balancing REACH compliance, lifecycle GHG footprint, and regulatory risk. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):992-1006.
141. Okojie JS, Filani OM, Ike PN, Okojokwu-Idu JO, Nnabueze SB, Ihwughwavwe SI. Integrating AI with ESG metrics in smart infrastructure auditing for high-impact urban development projects. International Journal of Multidisciplinary Futuristic Development. 2023; 4(1):32-44. Doi: https://doi.org/10.54660/IJMFD.2023.4.1.32-44
142. Okojie J, Ike P, Idu J, Nnabueze SB, Filani O, Ihwughwavwe S. Predictive analytics models for monitoring smart city emissions and infrastructure risk in urban ESG planning. International Journal of Multidisciplinary Futuristic Development. 2023; 4(1):45-57. Doi: https://doi.org/10.54660/IJMFD.2023.4.1.45-57
143. Okonkwo CS, Agbabiaka J, Ogunwole O, Mayo W, Okeke OT. Model for demurrage elimination and port logistics efficiency in emerging economies. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(5):552-562. Doi: https://doi.org/10.54660/IJMRGE.2020.1.5.552-562
144. Okonkwo CS, Agbabiaka J, Ogunwole O, Mayo W, Okeke OT. Conceptual model for materials readiness and maintenance-driven supply chain performance. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):584-594. Doi: https://doi.org/10.54660/IJMRGE.2021.2.6.584-594
145. Okonkwo CS, Ahiaeke Patrick MC, Okeke OT, Mayo W. Framework for integrating IT systems engineering with supply chain operations. International Journal of Advanced Multidisciplinary Research and Studies. 2023; 3(6):2580-2589. Doi: https://doi.org/10.62225/2583049X.2023.3.6.5500
146. Okonkwo CS, Mayo W, Okeke OT. Conceptual model for asset lifecycle management and inventory visibility. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2023; 10(1):809-824. Doi: https://doi.org/10.32628/CSEIT2391568
147. Okonkwo CS, Ogunwole O, Okeke OT. Framework for strategic procurement optimization in oil and gas operations. Iconic Research and Engineering Journals. 2018a; 1(7):153-168. Doi: https://doi.org/10.64388/IREV1I7-1713119
148. Okonkwo CS, Ogunwole O, Okeke OT. Model for inventory availability and plant uptime improvement in energy facilities. Iconic Research and Engineering Journals. 2018b; 2(4):160-172. Doi: https://doi.org/10.64388/IREV2I4-1713120
149. Okonkwo CS, Ogunwole O, Mayo W, Okeke OT. Framework for regulatory-compliant procurement in high-risk energy environments. International Journal of Multidisciplinary Research and Growth Evaluation. 2021; 2(6):595-605. Doi: https://doi.org/10.54660/IJMRGE.2021.2.6.595-605
150. Okonkwo CS, Ogunwole O, Okeke OT, Mayo W. Conceptual framework for cost reduction through contract negotiation and vendor governance. Iconic Research and Engineering Journals. 2019; 2(9):468-482. Doi: https://doi.org/10.64388/IREV2I9-1713121 Marketing Analytics and AI-Driven Marketing Automation
151. 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. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2020; 7(5):371-389.
152. Omoegun GO, Sunday EA, Essien MA, Oluokun OA. Vibration-based condition monitoring of rotating machinery using LabVIEW. International Journal of Scientific Research in Civil Engineering. 2023; 7(6):82-108.
153. OREDA Participants. OREDA: Offshore and Onshore Reliability Data Handbook. Trondheim: SINTEF and NTNU.
154. Oshevire P, Eyenubo OJ, Amayo B. Voltage control in the presence of distributed generation. ATBU Journal of Science, Technology and Education. 2017; 5(2):165-173. Project Management and Governance for Multinational Infrastructure and Energy Projects.
155. Oyeleye AO, Eyetsemitan RA, Ambali KB, Fadayomi O. Reducing client onboarding cycle time in small professional services firms: A Lean Six Sigma process redesign framework. Gyanshauryam, International Scientific Refereed Research Journal. 2022; 5(2):467-498. Doi: https://doi.org/10.32628/GISRRJ225357 Financial Fraud, Audit, and Risk Analytics
156. SAE International. SAE JA1011, Evaluation Criteria for Reliability-Centered Maintenance (RCM) Processes. Warrendale, PA: SAE International.
157. SKF Group. Bearing Damage and Failure Analysis. Gothenburg: SKF, publication guidance for grease sampling and analysis in rolling bearings.
158. Sunday EA, Omoegun GO. Smart fault detection in HVAC systems using sensor-based monitoring. International Journal of Scientific Research in Science, Engineering and Technology. 2022; 7(4):380-403.
159. Sunday EA, Omoegun GO, Essien MA, Oluokun OA. Thermodynamic efficiency and control strategies in residential air conditioning systems. International Journal of Scientific Research in Civil Engineering. 2019; 3(3):52-76.
160. Sunday EA, Omoegun GO, Essien MA, Oluokun OA. Transitioning from reactive to predictive maintenance in mechanical systems. International Journal of Scientific Research in Computer Science, Engineering and Information Technology. 2020; 6(6):425-447.

Autonomous Mobile Robotics and Warehouse Automation.
161. Tonoyan A, Dada O, Ayivi-Donkor SS. Advances in demand forecasting: Machine learning algorithms for revenue projection and financial planning accuracy. Gyanshauryam, International Scientific Refereed Research Journal. 2021a; 4(1):282-317.
162. Tonoyan A, Dada O, Ayivi-Donkor SS. Predictive cash flow modeling in retail: A review of advanced forecasting and working capital optimization. Shodhshauryam, International Scientific Refereed Research Journal. 2021b; 4(3):366-397.
163. Tonoyan A, Dada O, Ayivi-Donkor SS. Advances in geospatial analysis: Predictive analytics methods for store location selection and market entry return on investment. International Journal of Marketing and Communication Studies. 2022a; 6(2):78-105. Doi: https://doi.org/10.56201/ijmcs.v6.no2.2022.pg78.105
164. Tonoyan A, Dada O, Ayivi-Donkor SS. Algorithmic process optimization and cost reduction: A review of simulation modeling and financial impact assessment. Journal of Accounting and Financial Management. 2022b; 8(8):139-169. Doi: https://doi.org/10.56201/jafm.vol.8.no8.2022.p139.169
165. Tonoyan A, Dada O, Ayivi-Donkor SS. A conceptual framework for retail asset valuation: Integrating quantitative pricing and multi-unit financial performance prediction. Journal of Accounting and Financial Management. 2023; 9(12):218-250. Doi: https://doi.org/10.56201/jafm.v9.no12.2023.pg218.250
166. Yeboah BK, Ike PN. Programmatic strategy for renewable energy integration: Lessons from large-scale solar projects. International Journal of Multidisciplinary Research and Growth Evaluation. 2020; 1(3):306-315. Doi: https://doi.org/10.54660/.IJMRGE.2020.1.3.306-315