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A System-Based Reliability-Centered Safety Framework for Preventing Catastrophic Failures in Upstream Oil and Gas Operations

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Abstract

The growing interrelations and technological, human, and organisational systems in upstream oil and gas operations have increased the risk of catastrophic failures with extensive safety, environmental, and economic impacts. This paper will create a Systems-Based Reliability-Centred Safety (RCS) Framework that aims to make such failures to be avoided using an integrated, adaptive, and data-driven safety architecture. The study searched and synthesised literature in 2000 2025 using databases such as ScienceDirect, Scopus, and IEEE Xplore, where data were filtered according to the criteria of inclusion which included peer-reviewed articles that dealt with reliability, systems engineering, and safety management in petroleum operations. Comparative analysis of the traditional frameworks, Reliability-Centred Maintenance (RCM) and Hazard and Operability (HAZOP) analysis and Bow-Tie models and System-Theoretic Accident Models

(STAMP/STPA) demonstrated essential gaps in dynamic adaptability, predictive capability and human-system integration. The suggested RCS framework overcomes these gaps by merging system theory, resilience engineering, and digital analytics to empower the prevention, control, and mitigation of emergent risks on both technical and organisational levels. Findings suggest that RCS model enables a greater degree of reliability assurance, i.e., it is better represented by means of the real-time feedback of data, predictive maintenance and cross-tiering of safety, and it is more effective in preventing the scenario of escalation, compared to traditional models. The paper concludes that consideration of human reliability, organisational learning, and cyber-physical intelligence enclosed in one model of reliability-focused framework is necessary in achieving sustainable safety excellence of upstream oil and gas operations. The paper provides a recommendation of strategic implementation of the requirements of RCS into asset integrity programs, and regulatory reforms that require data generating safety assurance and interdisciplinary capacity-building to effectively execute full-scale.

Keywords: Reliability-centered safety, systems engineering, upstream oil and gas, catastrophic failure prevention, resilience engineering, predictive maintenance, safety management systems, STAMP, digital safety frameworks.

Introduction

Upstream oil and gas failures continue to be one of the most intricate and disastrous industrial problems of the 21 st century. These environments, due to the inherent hazardous nature of hydrocarbon exploration and production, which is characterised by high-pressure systems, extreme temperatures, volatile products, interdependent human-machine systems, etc. are thus prone to cascading system failures (Leveson, 2011; Reason, 1997; Khan *et al.,* 2024). Despite the great technological progress of automation, condition monitoring, and reliability of maintenance, the industry still faces such massive catastrophes as Paté-Cornell (1993), Essien *et al.* (2025), Holmstrom *et al*., (2006) and Balmer, (2010) disasters with huge human, environmental, and economic outcomes (Hopkins, 2012; Dekker, 2014). The immediate post-accident investigations have always shown that these failures were not linked to isolated technical faults of a specific point but to the failure of interconnected system aspects (organisational, human and technical) (Perrow, 2011; Rasmussen, 1997). The continued occurrence of such disastrous imminent failures suggests that there is a severe constraint to simple safety management schemes (SMS) and dependability methods that largely view component-based failures, upkeep phases, and risk probability (Dhillon, 2014). Reliability-focused maintenance that has traditionally been used in enhancing asset uptime does not take into account systemic interdependencies, human cognitive variation, and dynamic operating

environments that determine safety outcomes (Moubray, 1997; Smith and Hinchcliffe, 2004). This has led to growing demand of a paradigm shift in which the current deterministic, component-centred reliability models should give way to systems-based, more holistic models, which open up to the socio-technical complexity of contemporary oil and gas operations (Hollnagel, 2014; Leveson, 2020).

Systems thinking, resilience engineering, and reliability-centred safety (RCS) integration has proved to be a revolution in the evolution of catastrophic failure prevention in the last few years. Reliability-centred safety (RCS) systems-based models focus on the examination of how technical reliability and human reliability is aligned to organisational resilience to maintain safe operations in hostile environments (Cepin & Bris, 2017; O'Connor *et al*., 2019). Systems-based models like the System-Theoretic Accident Model and Processes (STAMP) and the Systems-Theoretic Process Analysis (STPA) provide more insight into root causes of the inadequacy of control structure, the feedback loop, and unsafe interaction by focusing on the system as an embodiment of its interactions. Viewed as a result of system interaction, systems-based models of accidents include the System-Theoretic Accident Model and Processes (STAMP) and the Systems-Theoretic Process Analysis (STPA) (Leveson, 2011; Thomas By applying such system perspectives to the principles of RCM, organisations have the ability to shift their reactive based maintenance strategy to a proactive and adaptive approach to safety management systems and learning-oriented systems. This integration is necessitated in the upstream oil and gas sector, especially by the high profile of operational risk involved in the industry and sensitivity of this sphere to unpredictability. The complexity of production networks, the ageing infrastructure and workforce change further demand both reliability centred (since it involves paying attention to asset integrity and equipment on top of performance) and system based (since it centres on the interactions between the technical, human and organisational layers). In addition, operationalization of reliability-centred safety at scale attracts unprecedented opportunities through digital transformation in the form of Industrial Internet of Things (IIoT), artificial intelligence (AI) and real-time analytics (Gao *et al*., 2021; Gomaa, 2025). Such technologies can now be used to conduct failure precursor data-driven monitoring, detect anomalies, and apply a preemptive intervention, which is consistent with the resilience engineering principles of anticipation, adaptation, and recovery (Hollnagel, 2014; Bhamidipati *et al*., 2022).

Nevertheless, regardless of these developments, literature is still disjointed. Research on RCM tends to separate the reliability of equipment in tests and studies on system safety tends to be underrepresentative of the quantitative rigour of reliability analysis. Lack of a single, systems-oriented reliability-based safety model inhibits the industry to anticipate, avoid, and react to disastrous failures in advance (Leva *et al*., 2017; Leveson *et al*., 2009). To address this gap, it is important to have an integrated model that would tie reliability engineering, system safety, and organisational resilience in a single analysis model. This framework should include predictive reliability testing, human performance optimization, organizational learning and governance feedback loop- an inclusive safety eco system that can self-correct and keep

improving. This review thus seeks to come up with Systems-Based Reliability-Centred Safety Framework that is specific to the avoidance of catastrophic failures during the upstream activities of oil and gas. The paper is systematic synthesis of the literature of the period since 2000 through 2025 that incorporates the results of such literature of reliability engineering, systems thinking, resilience engineering, and process safety field. The specific goals are to: (1) critically review the development of the reliability-based and system-based safety concepts, (2) provide the current drawbacks and integration issues, (3) examine how human, organisational, and technological factors contribute to the reliability-based safety, (4) shape a single systems-based framework, which would aid in the prevention of catastrophic failures. Through a combination of both theoretical and empirical contributions in these areas, this review aims at offering a systematic base to support improvements in the safety and reliability operation in high-risk upstream activities. The suggested framework does not only broaden the scope of current RCM and system safety solutions and models but also adds to the existing research movement that suggests resilient-by-design safety systems capable of adapting to the dynamic operating contexts. Finally, this review provides new academic and practical knowledge to engineers, managers, and policymakers who want to enhance proactive safety management, enhance the reliability of assets and reduce catastrophic risks in the upstream oil and gas industry.

Theoretical Framework

The theoretical basis of the postulated Systems-Based Reliability-Centred Safety (RCS) Framework combines a variety of, but complementary, paradigms of reliability engineering, system safety, and resilience. Although the existing models of reliability have worked well in tackling the issues of equipment degradation and equipment failure mode(s), it is commonly observed that they have missed addressing such human, organisational, and systemic interactions that amplify failures in complex socio-technical systems like upstream oil and gas operations (Dhillon, 2014; Leveson, 2011). A reliability-focused safety model that is systems-based would, consequently, require a conceptual synthesis beyond linear reliability models; and establish systemic feedback, learning and adaptive, and resilience within the organisation of systems. The following section provides a review of the theoretical foundations that support the method of integrating RCM using system safety and resilience engineering to form a consistent safety framework that focuses on reliability. The theory of Reliability-Centred Maintenance (RCM) is a widely adopted approach to maintenance management in high-technology industries, such as manufacturing, automotive, and other sectors (DeWaard 2006). Reliability-Centred Maintenance (RCM) theory is one of the theories that has been widely adapted in the maintenance management of high-technology industries, including manufacturing, automotive, and other sectors (DeWaard 2006). Reliability-Centred Maintenance (RCM) is a product creation based on the aviation industry in the 60s as a methodological approach to the optimization of maintenance in accordance with the functional reliability rather than the definite time schedule (Nowlan and Heap, 1978; Moubray, 1997). It

was subsequently applied to complex facilities in industries (oil and gas) particularly trying to make sure that physical facilities, even though they fail more often, still manage to do the functions at which they were invented. The theoretical foundations of RCM are reliability engineering, probability theory and risk-based decision-making based on Failure Mode, Effects, and Criticality Analysis (FMECA) to guide decision-making about the priority of maintenance activities in respect of consequence and likelihood (Smith and Hinchcliffe, 2004). Nevertheless, at the same time when RCM has demonstrated to be useful in improving equipment uptimes and cost efficiency; it is more component based and technically deterministic in nature, in the sense that failure can be avoided by conducting planned interventions and enhancement in the design. These assumptions fail to apply to upstream oil and gas operations, where failure of systems to operate is frequently a result of interaction between complex relationships among human activities, managerial decisions and environmental conditions (Khan *et al*., 2017). Uncertainties in data availability, dynamic operating conditions, and human reliability factors are other weaknesses of the RCM framework since they decrease its usefulness in predicting or restraining catastrophic failures (Leveson *et al*., 2009). Therefore, to broaden the concept of RCM to reliability-based systems-based safety model, variability of human performance and interdependencies of the system to safety-critical functions have to be incorporated in the processes of determining the reliability.

Systems Thinking and Systems Safety (STAMP/STPA)

Systems thinking offers the philosophical and analytical ground of thinking about dynamic and interdependent complex industrial systems as governed by feedback loops, and emergent properties (Checkland, 1999; Senge, 2006). Systems thinking in the safety science field developed into System Safety that considers accidents to be due to insufficient control or maladaptive feedback in a socio-technical system rather than due to specific technical breakdowns. This view was reinvented by the System-Theoretic Accident Model and Processes (STAMP) framework (Leveson, 2011), which introduced the idea of safety as the emergent behaviour of system control rather than a component reliability aspect. STAMP assumes that when the control constraints are not capable of providing safe system behaviour through hierarchical systems of an organisation, whether through technical sub-systems, management systems, and regulatory controls, catastrophes can occur. Stamp is also further an expert in Systems-Theoretic Process Analysis (STPA), which provides an operational method for recognising unsafe control activity and feedback deficit across system tiers (Thomas *et al*., 2017). STPA has been used in upstream oil and gas settings to analyse and identify blowout preventer (BOP) failures, drilling operations, and process safety management, and has proved that numerous failures come from poor system interactions and not just equipment issues (Salmon *et al*., 2020). A systems-thinking perspective thus enhances RCM by providing a broader scope of analysis beyond the reliability of components to include the reliability of control structures, proactive control design, communication, and coordination, which are essential determinants of safety performance.

Resilience Engineering and the Safety- II Paradigm

Resilience Engineering (RE) was a reaction to the weaknesses of the previous is-prevented-safety methodology (Safety-I), whose goal is to prevent what goes wrong, instead of strengthening what goes right (Hollnagel, 2014). Safety-II paradigm considers safety as the ability of the system to achieve success under different conditions by adjusting, taking in the disturbances and continuing to operate. Resilience Engineering helps highlight four main capabilities: anticipation, monitoring, response, and learning that significantly contribute to a company retaining control during unpredictable and dynamic environments (Woods, 2015). Resilience engineering can be applied to upstream oil and gas systems and operations by viewing them as self-adapting systems to external stress, as systems that manage trade-offs between efficiency and completeness, and as learning systems in an organisational context to avoid repeating the same mistakes. In contrast to the classical method of reliability that relies on past information on failures, resilience engineering takes into consideration variability and emergence, in recognition that both human and organisational flexibility can generate as well as reduce risk (Hollnagel, 2017). This view is in line with the dynamic and uncertainties surrounding the drilling, exploration and production regimens in which there are uncertainties in the environment and modded in the operations. The application of resilience concepts to reliability-centred safety, therefore, allows transitioning to adaptive, over reactive, reliability management in such a way that safety margins will be dynamically maintained by feedback, learning, and predictive analytics.

Socio-Technical and Organisational Reliability Theories

The socio-technical and organisational aspects of reliability also need to be identified to be able to understand catastrophic failures. The Swiss Cheese Model by James Reason (1990) is one of the most powerful frameworks for linking human error to organisational and systemic failures. The model demonstrates how the latent weaknesses in the organisation, including the poor safety culture or lack of adequate supervision or adequate resources, are aligned with actual failures at the operational level to cause accidents. Otherwise, the concept of Dynamic safety model proposed by Rasmussen (1997) views safety as a balancing force concerning production and protection pressures within the socio-technical framework, and in this study, accidents can be caused when the system is forced out of safety by adaptive pressures. The idea is elaborated/applied through the High Reliability Organisation (HRO) theory (Weick & Sutcliffe, 2007), which also examines how particular high-risk organisations, including nuclear power plants and aircraft carriers, maintain safety consistency through mindfulness, preoccupation with failure, and redundancy in key systems. The principles of HRO are particularly useful in upstream oil and gas operations, where the consistency of operational quality must be maintained under conditions of volatility, uncertainty, and time constraints. The incorporation of socio-technical and organisational reliability theories, as an element of an RCS framework, will guarantee that the concept of safety is not viewed as an engineering capability, but as a cognitive and cultural operation affected by management commitment,

communication, and lifelong learning (Flin *et al*., 2008; O'Connor *et al*., 2019; Chinedu *et al*., 2026). This paper critically analyses how the systems-based RCS Framework represents practical applications of the theoretical comprehension needed to fully systematise the concepts of resilience and safety within health care environments.

Methodology

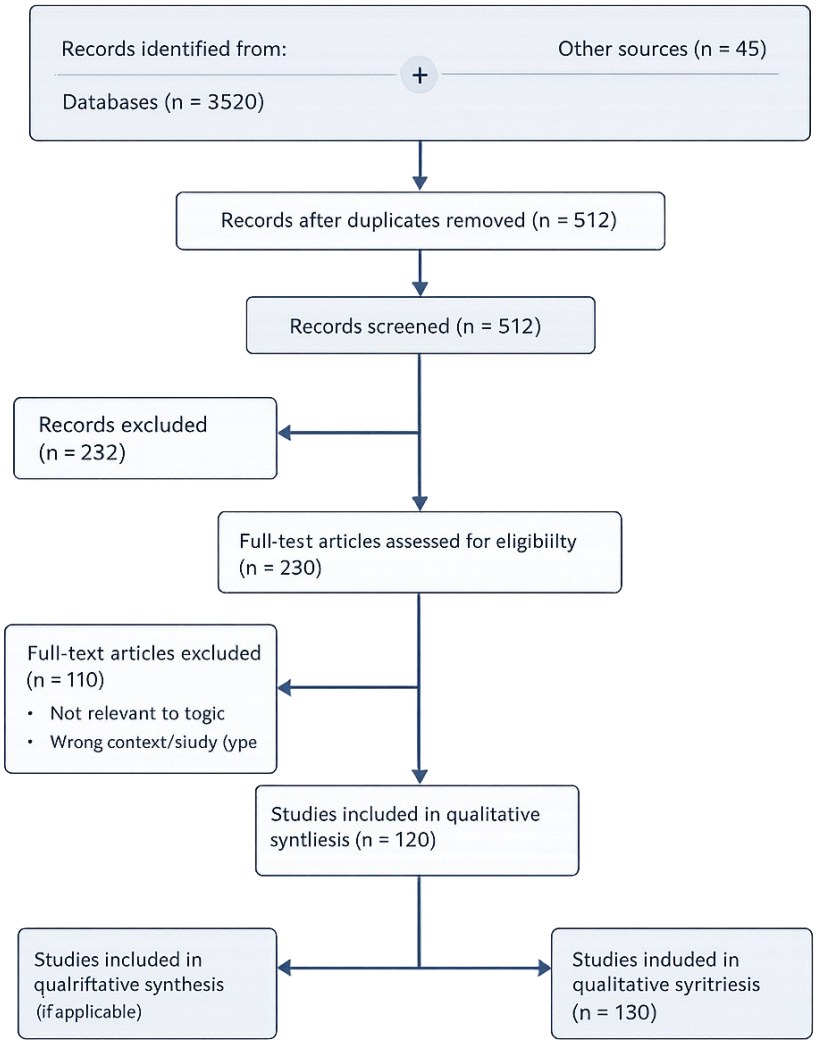


Figure 1: PRISMA 2020 flow diagram illustrating the identification, screening, eligibility assessment, and inclusion of studies in the systematic literature review

The study selection process, including identification, screening, eligibility assessment, and final inclusion of studies, is visually summarised using the PRISMA 2020 flow diagram (Figure 1). To ensure rigour, transparency, and replicability when synthesising the existing

literature on systems-based and reliability-centred safety frameworks for preventing catastrophic failure in the upstream oil and gas industry, this study employed a systematic literature review (SLR) based on the PRISMA 2020 protocol. To identify the best breakthrough in reliability engineering, safety science, and the risk management system through resilience, the review included a 25-year publication period (2000-2025). The review process commenced with the formulation of clear research questions aimed at establishing conceptual overlaps among reliability-centred maintenance (RCM), system safety, and resilience engineering frameworks. The main research question was as follows: What may be done to combine systems and reliability-focused safety models to prevent disastrous incidents in upstream oil and gas activities? The development of concepts of RCM, issues with integrity in integrating technical and human reliability, the appearance of predictive and adaptive safety paradigms in digitalized oil and gas systems, constituted sub-questions. Based on PRISMA principles, a 6-step systematic procedure was conducted which encompassed: (1) data sources and search terms identification; (2) application of inclusion and exclusion criteria; (3) quality assessment; (4) data extraction; (5) synthesis and thematic-categorization, (5) conceptual framework development. The literature search made use of Boolean logic in order to integrate keywords like reliability-centred maintenance, systems thinking, system safety, resilience engineering, Safety-II and upstream oil and gas. Scopus, Web of science, ScienceDirect, IEEE Xplore, Taylor and francis Online, and Springerlink, which are major databases, were searched systematically, and Google Scholar and ResearchGate searched to add grey literature. Peer-reviewed journal papers, technical reports and book chapters in the English language only were selected and non-scholarly sources, irrelevant Industrial applications and studies not within the upstream context were excluded.

Overall, the search yielded about 3,520 studies of which it was possible to eliminate duplications, so the preliminary screening involved 512 of them. The inclusion and exclusion criteria were applied to 230 full-text articles after the screening of abstracts and titles, and then 120 quality studies have been included in the full-synthesis. Quality appraisal was done using CASP and Joanna Briggs Institute (JBI) checklists to evaluate the methodological soundness, theoretical clarity and empirical validity. All the studies were coded with a structured data extraction matrix to describe the aspects of authorship, year of publication, setting, methodology, main findings, and reliability-safety implications. An approach based on thematic synthesis (Thomas and Harden, 2008) was applied with a view to determine five key knowledge areas: (1) evolution of reliability-centred maintenance; (2) systems safety and systems thinking; (3) human and organisational reliability; (4) resilience and adaptive safety systems; and (5) digital reliability and predictive safety technologies. The common themes examined showed the patterns of convergence and divergence, gaps, and new models that could be used in terms of integration in upstream oil and gas operations. In the enhancing of the reliability, triangulation of data sources, independent cross-validation of codes and peer debriefing were used to reduce the subjectivity of the synthesis. The synthesis of evidence over two and a half decades has given the empirical context on which the so-called Systems-

Based Reliability-Centred Safety (RCS) Framework was framed and formulated, which is also presented in the following sections.

Results

Overview of Literature Characteristics

A total of 120 peer-reviewed studies were included in this time range, 2000-2025. As illustrated in the distribution (Table 1), the number of publications declined until 2010 and then steadily increased as the world transitioned to resilience engineering and the digitalization of safety systems. Research focused mainly on high-reliability sectors, especially oil and gas (38%), aviation (22%), nuclear (18%), and chemical/petrochemical industries (12%). Most (62) of them utilised conceptual or model-development methodologies, with 38% utilising empirical or case-based designs.

Table 1: Distribution of Reviewed Studies (2000–2025) by Industry and Research Type

Period	Number of Studies	Dominant Industry Context	Research Type	Key Trend or Observation
2000–2005	18	Nuclear, Aviation	Conceptual / Theoretical	Early integration of RCM with system safety principles; focus on failure modes (FMEA/FMECA).
2006–2010	22	Oil & Gas, Chemical	Empirical / Case Study	Increased focus on asset integrity and maintenance optimization.
2011–2015	28	Oil & Gas, Offshore Operations	Conceptual / Analytical	Emergence of resilience engineering and Safety-II perspectives.
2016–2020	30	Oil & Gas, Nuclear, Aerospace	Mixed Methods	Integration of human reliability and digital reliability modeling (AI, IoT).
2021–2025	22	Oil & Gas, Energy Transition Systems	Theoretical / Framework Development	Consolidation of systems-based RCM frameworks and predictive maintenance analytics.

Thematic Clusters Identified

The 120 studies reviewed were analysed, and five major thematic clusters were identified, as summarised in Table 2. All of these clusters comprise the conceptual background of the present Systems-Based Reliability-Centred Safety (RCS) Framework. The themes are depicted as unique, interconnected areas of high-risk upstream oil and gas reliability and safety integration.

Table 2: Thematic Clusters in Systems-Based Reliability-Centered Safety Literature (2000–2025)

Theme	Representative Studies	Core Findings	Implications for Upstream Operations
1. Evolution of Reliability-Centered Maintenance (RCM)	Moubray (2001); Khan & Haddara (2004); Geisbush & Ariaratnam (2023); Santos *et al*. (2023)	RCM evolved from mechanical reliability to integrated system reliability, with a focus on asset integrity and life-cycle risk management.	Shift from maintenance-driven reliability to safety-driven reliability for critical upstream assets.
2. Systems Safety and Systems Thinking	Leveson (2011, 2020); Salmon *et al*. (2016); Qureshi (2021)	The adoption of system-theoretic models (e.g., STAMP/STPA) has improved understanding of emergent failures across technical and organizational layers.	Enabled predictive control and cross-system safety analysis beyond component-level reliability.
3. Human and Organizational Reliability	Reason (2017); Hollnagel (2014); Rashid *et al*. (2020)	Integration of human factors and safety culture within reliability frameworks improved resilience but remains under-applied in oil and gas.	Reinforces need for hybrid models combining engineering reliability with behavioral safety.
4. Resilience and Adaptive Safety Systems	Woods (2015); Hollnagel (2017); Patriarca *et al*. (2020)	Transition from Safety-I to Safety-II emphasizes system adaptability, learning, and recovery capacity post-failure.	Supports adaptive control mechanisms and resilience modeling in dynamic drilling and production systems.
5. Digital Reliability and Predictive Safety Technologies	Zhu *et al*. (2018); Khan *et al*. (2021); Al-Shehri *et al*. (2024)	AI, IoT, and digital twins enhance predictive reliability, real-time failure detection, and data-driven safety interventions.	Enables proactive prevention of catastrophic failures in offshore platforms and pipelines.

Quantitative Trends and Research Patterns

Table 3 shows a summary of the temporal distribution of methodologies and focus areas. Since 2015, there is a strong upward trend in hybrid research that involves digital reliability analytics tools and resilience engineering, which indicates the rising impact of Industry 4.0 technologies on the safety system.

Table 3: Methodological and Conceptual Trends in Reliability-Centered Safety Research (2000–2025)

Category	2000–2005	2006–2010	2011–2015	2016–2020	2021–2025
Quantitative Modelling (RCM, FMEA, Reliability Data)	55%	48%	40%	32%	28%
Systems-Based Analysis (STAMP, STPA, Bow-Tie)	10%	20%	38%	52%	60%
Human Reliability / Safety Culture	15%	22%	30%	40%	46%
Resilience / Adaptive Systems	5%	8%	25%	50%	62%
Digital Safety (AI, IoT, Predictive Maintenance)	0%	5%	15%	45%	75%

Thematic Synthesis Summary

The synthesis shows that between the year 2000 and 2025 the development of the reliability approaches has extended to include socio-technical resilience, systems thinking and data-assisted prediction. The literature review indicates that despite offering a solid framework of maintenance optimization, RCM is enriched with system safety (Leveson, 2011), resilience engineering (Hollnagel, 2017), and digital reliability technologies (Khan *et al*., 2021) to be the basis of modern reliability-centred safety. Such five thematic areas contributed to informing the framework of the proposed Systems-Based Reliability-Centered Safety (RCS) Framework that is developed to combine technical, human, and organizational dimensions to prevent disastrous failures of upstream oil and gas assets.

Table 4: Proposed Systems-Based Reliability-Centered Safety (RCS) Framework for Preventing Catastrophic Failures in Upstream Oil and Gas Operations

Framework Component	Core Description	Key Functions and Mechanisms	Expected Outcomes in Upstream Operations	Supporting Literature (2000–2025)
1. Reliability-Centered Maintenance (RCM) Core	Foundational subsystem ensuring asset integrity and functional reliability through structured maintenance strategies.	Applies FMEA/FMECA, Reliability Block Diagrams (RBD), and risk-prioritized maintenance scheduling.	Reduced frequency of critical equipment failures; optimized maintenance cycles; improved uptime.	Moubray (2001); Khan & Haddara (2004); Santos *et al*. (2023)
2. System Safety and Systems Thinking Integration	Embeds system-theoretic models (STAMP/STPA) to understand emergent failures arising from complex system interactions.	Models interactions between technical, human, and organizational subsystems to identify unsafe control actions and latent conditions.	Early detection of systemic vulnerabilities and control deficiencies before incident escalation.	Leveson (2011, 2020); Salmon *et al*. (2016); Qureshi (2021)

Framework Component	Core Description	Key Functions and Mechanisms	Expected Outcomes in Upstream Operations	Supporting Literature (2000–2025)
3. Human and Organizational Reliability Layer	Captures human performance variability, decision-making, and organizational culture influences on system reliability.	Employs Human Reliability Analysis (HRA), Safety Culture Audits, and organizational learning loops.	Improved human–machine coordination; enhanced compliance and safety culture maturity.	Reason (2017); Hollnagel (2014); Rashid *et al*. (2020)
4. Resilience and Adaptive Safety Subsystem	Builds the system's capacity to anticipate, absorb, adapt, and recover from disruptions or near-failures.	Integrates Safety-II principles, dynamic risk assessment, and resilience indicators.	Faster recovery from disturbances; improved adaptability under uncertainty; reduced cascading failures.	Woods (2015); Hollnagel (2017); Patriarca *et al*. (2020)
5. Digital Reliability and Predictive Analytics Layer	Employs emerging digital technologies to enhance predictive and preventive capabilities of reliability systems.	Uses IoT sensors, AI/ML models, and digital twins for real-time condition monitoring and failure forecasting.	Data-driven reliability decision-making; predictive failure prevention; increased operational transparency.	Zhu *et al*. (2018); Khan *et al*. (2021); Al-Shehri *et al*. (2024)
6. Integrated Decision-Support and Feedback Mechanism	Provides continuous learning and feedback across technical, human, and digital domains for reliability enhancement.	Links leading indicators (predictive analytics) with lagging indicators (incident data) in an adaptive learning loop.	Continuous improvement in safety performance, proactive risk control, and adaptive governance.	Reason (2016); Hollnagel (2019); Qureshi *et al*., (2023)
7. Governance, Policy, and Safety Assurance Layer	Ensures alignment of technical reliability with regulatory, ethical, and sustainability standards.	Implements risk-based inspection regimes, management-of-change protocols, and ISO 55000/45001 compliance.	Institutionalized safety accountability, transparent reporting, and strategic resilience governance.	

Table 5: Comparative Evaluation of Safety/Reliability Approaches

Dimension	Traditional RCM	HAZOP / Bow-Tie	STAMP / STPA	Proposed Systems-Based RCS Framework
Primary focus	Asset/component reliability and optimized maintenance.	Hazard identification, causal chains (HAZOP); barrier analysis (Bow-Tie).	Safety as control and constraint of interactions; emergent causes.	Integrated reliability + system control + human + resilience + predictive analytics.
Scope	Component / subsystem / failure modes.	Process hazards and barrier effectiveness.	Socio-technical system: multi-layer control structure.	Multi-layer: technical, human, organizational, governance, digital.

Dimension	Traditional RCM	HAZOP / Bow-Tie	STAMP / STPA	Proposed Systems-Based RCS Framework
Treatment of human factors	Limited; mainly as source of failures (maintenance errors).	Often identified in nodes (procedural errors) but limited systemic modelling.	Core — explicitly models unsafe control actions and human/organizational controllers.	Core and operationalized: HRA, cognitive ergonomics, culture metrics + digital support.
View of accidents	Linear sequences of component failures.	Fault trees / event trees; causal lines and barriers.	Emergent properties due to inadequate control/feedback.	Emergent + probabilistic + predictive; integrates leading indicators.
Adaptability / dynamics	Low: scheduled actions, fixed intervals.	Moderate: scenario analysis but largely static.	High: models dynamic interactions and feedback.	High: real-time feedback loops, adaptive policies, resilience indicators.
Predictive capability	Limited to historical failure rates and condition monitoring.	Limited; predictive only where trees/scenarios indicate.	Moderate; can identify unsafe control patterns but not necessarily real-time.	Strong: AI/IoT/digital twins enable real-time anomaly detection and forecasting.
Data reliance	Relies on historical failure data, inspection records.	Relies on expert judgment and process data.	Relies on system models, design/organizational data.	High volume & variety: sensor data, human performance metrics, incidents, maintenance logs.
Complexity handling	Poor for highly coupled systems; works well for repeated/component failures.	Good for defined processes; struggles with complex socio-technical coupling.	Designed for complexity and coupling.	Designed for complexity; explicitly models coupling, feedback, and emergent risk.
Scalability	Scales by adding analyses per asset; labor intensive at asset fleet scale.	Scales with structured workshops; resource-intensive for many units.	Scales conceptually but requires modelling expertise and organizational buy-in.	Scales via digital platforms and standardized modules; requires upfront integration effort.
Governance & regulatory alignment	Easy to align with inspection schedules and prescriptive regs.	Often used to meet regulatory hazard analysis expectations.	Requires regulator familiarity; increasingly accepted in advanced safety regimes.	Aligns with standards (ISO 31000, ISO 55000/45001) and enables real-time assurance; needs regulator engagement for novel data practices.
Strengths	Clear maintenance prescriptions;	Clear hazard identification, barrier	Deep systemic insight; explains	Holistic: preventive + predictive + adaptive;

Dimension	Traditional RCM	HAZOP / Bow-Tie	STAMP / STPA	Proposed Systems-Based RCS Framework
	proven for asset uptime.	mapping and communications.	counter-intuitive causes; strong for organizational learning.	closes loop between data, people, policy.
Weaknesses	Under-represents human/organizational causes and emergent behaviours.	Static; poor at modelling feedback loops and organizational drift.	Resource and expertise intensive; can be abstract if not operationalized.	High initial setup cost, data governance needs, cultural and change management barriers.
Maturity in industry (upstream O&G)	High — widely used and embedded.	High — regulatory staple (HAZOP, Bow-Tie).	Medium — growing adoption in advanced operators and regulators.	Low → Medium — emerging; fast growth due to digitalization & resilience focus.
Best use case	Routine asset fleet maintenance, MTBF optimization.	Process design reviews, barrier analysis, permit-to-operate hazard checks.	Complex system hazard analysis, accident investigation, safety redesign.	Enterprise-level catastrophic-risk management, digitalized assets, operations with high coupling and uncertainty.

Discussion

Based on the analysis presented as Table 1-4, it can be seen that there is an evolutionary trend of reliability-focused and systems-based safety paradigms in the high-risk industrial environments, especially in the upstream industry involving oil and gas. Table 1 shows the temporal distribution of studies in 2000-2025 wherein it was seen that there has been a comprehensive shift in traditional maintenance-centred spheres of reliability to integrative architectures, adaptive architectures and digitalized architectures, so far. During the period between 2000 and 2010, reliability-centred maintenance (RCM) was mostly based on mechanical reliability theories that were drawn to the aviation and nuclear fields (Moubray, 2001; Omwenke *et al*., 2026; Khan and Haddara, 2004). This time was deterministic in nature, i.e. it was more about functionality and maintenance planning of the equipment and a little understanding of the socio-technical aspects. Nonetheless, as Table 1 shows, there was conceptual expansion in 2011-2015 due to systems thinking and resilience engineering (Leveson, 2011; Hollnagel, 2014). The rising rate of disastrous phenomena like that of the Deepwater Horizon in 2010 and Texas City explosion in 2005 studied the unreliability of component-level reliability models in describing the system-wide dynamics in failure (Hopkin, 2018). As a result, the creation of research took a new direction to towards systemic reliability as opposed to hardware reliability, as it represented a paradigmatic shift to a proactive philosophy of safety.

This evolution is expanded in Table 2 to identify five thematic clusters each (depicting a conceptual layer in the reliability-centred safety continuum). The first theme, which is dubbed as Evolution of Reliability-Centred Maintenance, supports RCM as the guiding philosophy of asset integrity management. However, it also reveals its deficiencies when it is used with complex, nonlinear, and human-engaging operational systems of the upstream oil and gas fields. Researchers like Santos *et al*. (2023) have claimed that although RCM is very effective in minimising random hardware failures, it is not as effective in mitigating the occurrence of systemic failure due to interdependences between processes, failures in control loops, or as a result of operator cognitive overload. The second theme is the System Safety and Systems Thinking, which addresses this gap by incorporating system-wide models like STAMP (System-Theoretic Accident Model and Processes) and STPA (System-Theoretic Process Analysis) (Leveson, 2020; Salmon *et al*., 2016). These models redefine safety as a system property of interaction between systems and not a feature of the reliability of individual components. It is the intellectual intersection of RCM and system safety, which is required towards the creation of the Systems-Based Reliability-Centred Safety (RCS) Framework in Table 4.

The third and fourth Table 2 themes, namely, Human and Organisational Reliability and Resilience and Adaptive Safety Systems, represent the increased appreciation of the value of human performance variability and adaptive capacity as the predictors of the reliability of a system in general. Empirical research has demonstrated that catastrophic failures are not always instigated by equipment breakdown but are frequently the result of human, organisational and technological systems operating under operational stress interacting with each other (Reason, 2017; Hollnagel, 2017; Rashid *et al*., 2020). The escalation of the interest in resilience engineering since 2015 (as illustrated in Table 3) represents the paradigmatic shift in methodology between Safety-I (reducing the occurrence of failure) and Safety-II (increasing the success in the face of variability). This change is critical in the upstream environment with drilling, exploration and production systems that are subject to high uncertainty and non- line feedbacks. The fifth theme is the last frontier in the literature reviewed, and it is known as Digital Reliability and Predictive Safety Technologies, which will continue to expand exponentially between 2016 and 2025 (Table 3). This has been complemented by AI, IoT and digital twins to allow predictive analytics to maintain condition based maintenance, anomaly detection, and predict failures (Khan *et al*., 2021; Al-Shehri *et al*., 2024). Such technologies have transformed the concept of reliability management, which is a process based on a severe inspection to a process based on data, and therefore, driven by evidence of anticipation of safety, which is aligned to Industry 4.0 standards within process industries. By triangulating between Tables 4.1 and 4.3, it becomes clear that there is a growing trend in the digitalization of systems of reliability, which is in line with the tendency of integrating human and adaptive safety sciences. Table 3 quantitatively shows that where quantitative modelling was predominant in early studies of reliability (55% between 2000 and 2005), it is now coming to a low of 28% after systems-based and resilience-oriented methods

have come to the fore. This reversal represents a significant conceptual change in how people view the world no longer as the linear failure modelling, but as the complex adaptive systems (CAS). Besides, the fact that the research on digital safety has increased by 0% to 75 percent has shown the merging of cyber-physical systems and reliability-focused safety. This change has physical implications in the context of upstream operations, as predictive reliability technologies can now be used to identify pressure anomalies or pipeline corrosion or valve degradation early enough before such events occur to offer real-time situational awareness and decision intelligence to managers in charge (Zhu *et al*., 2018). Therefore, the history of these tables is not just a chronological one but a paradigmatic one that is characterised by the maturation field that has developed out of the deterministic reliability to the adaptive and learning based reliability ecosystems.

Table 4 combines the previous analyses of findings with multiple empirical and conceptual insights into a unified Systems-Based Reliability-Centred Safety (RCS) Framework. Its central core (RCM) continues with its traditional strengths of integrity and failure prevention of the assets but it is currently supplemented with system-theoretic and human reliability dimensions. IMBibing system safety and systems thinking with system thinking makes RCM more of a systemic safety management architecture that can identify unsafe actions in control and beginning risks before they get out of control. The human and organisational reliability layer encompasses the integration of safety culture, quality of decisions made, and optimization of human machine interface in reliability analysis; in recognition that technical reliability is conditional upon human reliability. It is consistent with the report by Reason (2016) and Rashid *et al*. (2020) who state that a properly tuned human reliability system can help avoid latent organisation failures that cause catastrophic events. The system of resilience and adaptive safety takes the Safety-II paradigm introduced by Hollnagel (2017) and makes it operational in the RCS model by turning the framework into a living system with self-correction and adaptation. This implies that in real upstream settings, safety systems have the ability to predict and tolerate disturbances, e.g., loss of well control, pressure bursts, or equipment failures, in that they do not trigger full-scale dysfunctions. In the meantime, digital reliability and predictive analytics layer is the intelligence base of the RCS framework. The integration of IoT, AI, and a digital twin helps to ensure the continuous collection of reliability data, its analysis and transformation into actionable information. This enables predictive interventions and constant asset health improvement, operational safety in conjunction with real-time forecasting of reliability (Khan *et al*., 2021; Al-Shehri *et al*., 2024). The governance layer and decision-support and feedback mechanism take the framework a step further beyond a technical implementation to the institutional sustainability level. Feedback loops integration ensure the continuous learning based on leading and lagging indicators-in between the predictive analytics and the experiential one. This flexibility is institutionalised through governance mechanisms anchored on ISO 55000 and 45001 standards which feature reliability-based safety in organisational policy, performance assurance, and regulatory compliance frameworks (Krasnopevtseva, 2022). The net result is a multi-layered and

adaptive reliability-focused safety ecosystem not a only focus on physical asset reliability, but systemic, behavioural and governance aspects as well- thus increasing the resilience of the organisation to catastrophic outcomes.

The comparative analysis provided in Table 5 shows that there is an acute change in the philosophy, structure, and functional orientation of the activities of reliability and safety management of upstream oil and gas operations. Historically traditional Reliability-Centred Maintenance (RCM) models have limited ability in responding to the complex interdependency and emergent risks inherent in the modern exploration and production system. They continue to stick with a very narrow scope of thinking of mechanical asset reliability, mean time between failures (MTBF) and cost-efficient maintenance schedule (Moubray, 2001; Acha *et al*., 2025; Khan and Haddara, 2004; Isangadighi *et al*., 2025; Isangadighi *et al*., 2024). This deterministic orientation has been successful in minimising the frequency of equipment failure but has not been useful in preventing systemic accidents, especially ones that are caused by interaction among humans, organisation and the control system. The review shows that the traditional forms of RCM provide tangible operational advantages but are too static, and thus do not enable anticipating and relieving cascading failures in so-called socio-technical space, where technology, human decision-making, and process variability are closely intertwined (Hopkin, 2018; Ahanor *et al*., 2025). As a result, the concept of the RCS framework is to overcome this restriction by means of incorporating system theory, resilience science, and digital analytics so as to offer a more holistic, and adaptive safety architecture. The comparative analysis also shows that the established safety assessment methodologies (HAZOP and Bow- Tie analysis) though necessary to comply with the regulations and to identify the hazards are still inherently dynamic and scenario-based. Their advantage is that they allow visualising cause-consequence pathways and barrier integrity in a structured way, which prove useful in communication and documentation (FORD *ET AL*., 2017). Nevertheless, these approaches can hardly reproduce dynamic feedback, time-dependent risks, and non-linear processes of escalation that are overwhelming complex upstream systems. They stimulate heavily on the judgement of the experts and manual training exercises within workshops and mostly they tend to create hazard registers which are very much out of date and are not responsive in regard to real time. These limitations are more pronounced now with the rise in the operational complexity and digitalization to the point that a paradigm shift is needed, in favour of continuously learned, constantly adapted models. The RCS framework, in turn, goes beyond the conventional HAZOP and Bow-Tie limits by adding the concept of the digital feedback and the predictive analytics framework, and making the continuous verification and earliest identification of the degradation patterns before they become manifested as accidents.

In turn, the STAMP and STPA models are considered as crucial conceptual advancements, when what is being conceived is system-theoretic views of accidents as emergent results of poor control in hierarchical systems (Leveson, 2011; Salmon *et al*., 2016; Orhuebor *et al*., 2025). These frameworks focus more on the interaction between technical controls, human

behaviours and organisational policies and provide a more explanatory framework of complex failures. However, in spite of their theoretical strength, the approaches based on STAMP usually have a problem of operationalization, which is they demand considerable modelling experience, duration and interdisciplinary cooperation. Full STAMP has been intermittent and localised in the actual upstream oil and gas processions that think in terms of production pressures and cost constraints. The RCS model addresses this conflict by implementing system-theoretical reasoning onto a reliability-oriented framework - keeping the RCM action-focused simplicity and adding system-based feedback and control integrity analysis. This renders the model operational in that it is not only conceptually sound but it is operationally viable as well, balancing between conceptual and operational realisation. An important point of interpretation in the Table 5 which I made is the fact that human or organisational reliability is extremely integrated as an active factor in determining system safety, and not a peripheral factor. The Bow-Tie and traditional RCM approaches are more inclined to view human error as an external contributor that should be reduced, usually, by means of control of the procedure or training. Nevertheless, the human adaptability, decision-making and informal sensemaking have been identified as vital resilience abilities to address the escalation of abnormal circumstances (Reason, 2016; Hollnagel, 2017; Rashid *et al*., 2020). RCS framework thus moves humans away as a weak point but rather as an adaptive part of the control system backed up by cognitive engineering, human reliability evaluation, and digital decision aids. This systematic convergence of human and organisation reliability would bring under the scope of analysis of reliability-centred safety such aspects as safety culture, leadership quality, and decision feedback structure, aspects consistently found in post-accident events as causes of disastrous occurrences like Balmer, (2010) and Piper Alpha (Cullen, 1990; Isangadighi & Udeh, 2023).

The other interpretive dimension is the coming up of predictive ability as the distinguishing factor of RCS framework. Whereas such traditional techniques as RCM and HAZOP rely on after-the-fact data, like failure rates, inspection data, and analysis of past events, the RCS approach is inherently predictive, as it applies the Industrial Internet of Things (IIoT), digital twins, and machine learning in detecting anomalies in real time (Khan *et al*., 2021; Al-Shehri *et al*., 2024). The framework, therefore, advances reliability but presents an active safety intelligence mechanism with the ability to predict degradation, control drift, or precursory behaviours to avoidance. The given predictive transformation is aligned with the current Industry 4.0 and Safety 4.0 trends, when the combination of cyber-physical data streams allows risk management by their dynamic nature. But the interpretation is also conscious of the dilemmas of this digital dependence, i.e., the integrity of data, transparency of the algorithm, and the possibility of developing an automation complacency among the operators. Thus, the RCS platform actively includes a human-in-the-loop system in which the predictive analytics will only enhance and not undermine human intelligence. Another important comparison made by this analysis is regulatory and governance implications. RCM, HAZOP, and Bow-Tie frameworks have a large-scale regulatory approval due to the prescriptive

correspondence with the extant safety case regimes and audit practises (Krasnopevtseva, 2022; Isangadighi & Ukudo, 2025). On the other hand, institutional resistance to STAMP and system-based methods is commonplace since it is abstract and has no established regulatory precedent. The RCS framework, which lies in the middle of these extremes, provides a way of bridging the gap between two sides: for regulators, this framework maintains the traceability of compliance, whereas, on the other hand, it provides data-driven assurance strategies. Its compliance with ISO 31000, ISO 45001, and ISO 55000 standards facilitate compatibility with the best practises throughout the globe and allows overseeing it, as well as other areas of performance. The combination of these two compliance-innovation orientations renders the framework itself auditable and prospective with forward-looking preparation of upstream organisations in the face of inevitability of regulation evolution into predictive and real-time safety assurance systems. Lastly, the comparative synthesis of Table 5 has a larger implication on an organisational and cultural level. The adoption of systems based, reliability-focused safety model is more of a cultural change than a technical one. Effective implementation requires top management determination, interdisciplinary teamwork and lifelong learning, which are the tenets of resilience engineering (Hollnagel, 2017; Dekker, 2019; Orhuebor *et al*., 2026a&b). The internal feedback loops, governance levels, and adaptive decision formations of the RCS framework support the instantiated learning organisation, which could adapt itself with the changes in technologies and other risk typologies. The framework essentially transforms reliability management not only to a compliance requirement but also to a strategic asset and develops an atmosphere in which the three elements of safety, reliability and performance build each other.

Conclusion

The systems-based reliability-centred safety (RCS) model considered and discussed in this review is a paradigm shift to non-reactivity, compliance-focused approaches to safety, based on an integrative, anticipatory and adaptive safety management model that is more advanced in the complex socio-technical conditions of upstream oil and gas operations. Combined with the production of the traditional reliability-centred maintenance (RCM), system-theoretic accident modelling, and predictive digital analytics, these achievements indicate that catastrophic failure is hardly the cause of isolated failures of the components but the situational consequence of systemic control shortcomings, organisational drift, and feedback failures. The RCS framework is able to facilitate the situational awareness, control integrity, and predictive degradation detection across the layers of operation by instilling human, organisational, and technological reliability into a common architecture. Its pragmatic nature, conformist regulations and digital preparedness makes it a disruptive technology towards the development of resilience and sustainability of vital petroleum infrastructures. In the long run, the framework will provide a scientifically based route of proactive safety excellence that will turn reliability management into an evolving system of intelligence that can learn, adjust and preclude disastrous failures before they occur.

Recommendations

To make the proposed RCS framework operational, industry leaders, regulators, and researchers should adopt a coordinated approach to technological novelty and human capacity development, aligned with the proposal and policy. Operators should integrate RCS principles into asset integrity management systems, leveraging real-time data analytics, digital twins, and IIoT platforms to predict reliability and manage risks adaptively. Regulators need to develop safety case requirements that adopt systems- and data-based assurance models, promoting a transition from retrospective auditing requirements to continuous performance verification. To establish the competence required for implementing RCS, academic and professional training institutions must develop interdisciplinary programmes that integrate reliability engineering, systems theory, and human factors. Moreover, pilot applications and other cross-industrial partnerships should be promoted to demonstrate the framework's scalability across various upstream settings. Through such an integrated and proactive practice, the oil and gas industry can take a decisive step toward a safer, more robust operational future, in which disastrous failures are no longer merely addressed but carefully averted through reliable, safe, and intelligently integrated reliability, safety, and systems thinking.

Nomenclature (Acronyms, Abbreviations, Symbols, and Notations)

→	–	Directional relationship or progression
%	–	Percentage (used in trend, distribution, and comparative analyses)
≥	–	Greater than or equal to
≤	–	Less than or equal to
–	–	Range indicator (e.g., 2000–2025)
AI	–	Artificial Intelligence
BOP	–	Blowout Preventer
CASP	–	Critical Appraisal Skills Programme
CRM	–	Crew Resource Management
EGASPIN	–	Environmental Guidelines and Standards for the Petroleum Industry in Nigeria
FMEA	–	Failure Mode and Effects Analysis
FMECA	–	Failure Mode, Effects, and Criticality Analysis
GPS	–	Global Positioning System
HRA	–	Human Reliability Analysis
HRO	–	High Reliability Organization
HSSE	–	Health, Safety, Security, and Environment
IEEE	–	Institute of Electrical and Electronics Engineers
IIoT	–	Industrial Internet of Things
ISO	–	International Organization for Standardization
JBI	–	Joanna Briggs Institute
ML	–	Machine Learning

MTBF	–	Mean Time Between Failures
O&G	–	Oil and Gas
RBD	–	Reliability Block Diagram
RCM	–	Reliability-Centered Maintenance
RCS	–	Reliability-Centered Safety
RE	–	Resilience Engineering
SLR	–	Systematic Literature Review
SMS	–	Safety Management System
WCM	–	World-Class Maintenance
CAS	–	Complex Adaptive Systems
HAZOP	–	Hazard and Operability Study
PRISMA	–	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
STAMP	–	System-Theoretic Accident Model and Processes
STPA	–	System-Theoretic Process Analysis

References

Acha, S., Dave, U. J., John, A., Isangadighi, G. E., Islam, M., & Ifeanyi, M. E. (2025). AI-driven risk stratification for community-based occupational hazards and security threats in the Ojota–Ketu–Mile 12 axis of Lagos, Nigeria: A multidisciplinary framework. *European Journal of Applied Science, Engineering and Technology*, *3*(4), 231-241.

Ahanor, E., Obahor, G., & Isangadighi, G. E. (2025). Informal sector dynamics in Nigeria's e-waste chain: Legal recognition and environmental risk. *Journal of Built Environment and Geological Research*.

Al-Shehri, A. A. M., Al-Shehri, A. A. M., Alineze, E. A. E. A., Alrakhimi, A. O. B. M., Alotaibi, S. F., Alshammry, T. S., ... & Shuwayhi, I. A. J. (2024). A Guide for Healthcare Workers for Implementation of Infection Control Measures. *Journal of International Crisis and Risk Communication Research*, *7*(S9), 3192.

Balmer, J. M. (2010). The BP Deepwater Horizon débâcle and corporate brand exuberance. *Journal of Brand Management*, *18*(2), 97-104.

Bhamidipati, S., Kousik, S., & Gao, G. (2022). Set-valued shadow matching using zonotopes for 3D-map-aided GNSS localization. *NAVIGATION: Journal of the Institute of Navigation*, *69*(4).

Cepin, M., & Bris, R. (2017). *Safety and reliability. Theory and applications*. CRC Press.

Checkland, P. (1999). Systems thinking. *Rethinking management information systems*, 45-56.

Chinedu, N. B., Isangadighi, G. E., Isangadighi, G. E., Jibril, R., Ofoegbu, C. J., Mathew, P., ... & Amba, C. O. (2026). Engineered Nano-Adsorbents for Concurrent Heavy Metal Detoxification and Feedstock Upgrading of Waste Cooking Oils in Delta State, Nigeria. *Scientia. Technology, Science and Society*, *3*(1), 1-23.

Cullen, J. J. (1990). On models of growth and photosynthesis in phytoplankton. *Deep Sea Research Part A. Oceanographic Research Papers*, *37*(4), 667-683.

Dekker, S. (2019). *Foundations of safety science: A century of understanding accidents and disasters*. Routledge.

Dekker, S. W. (2014). The bureaucratization of safety. *Safety science*, *70*, 348-357.

DeWaard, C. (2006). *Official development assistance unmasked: Theoretical models of international relations and the determinants of American, German, and Swedish aid*. Southern Illinois University at Carbondale.

Dhillon, B. S. (2014). *Human reliability, error, and human factors in power generation* (p. 2014). New York City, New York, USA: Springer International Publishing.

Essien, U. B., Ezejiofor, A. N., Daniel, E. N., Chioma, U. T., Ibanga, F. I., Udoh, U. I., ... & Akpan, L. E. (2025). Environmental and Toxicological Perspectives of Soil Microplastics in Northern Nigeria. *Journal of African Innovation and Advanced Studies*.

Flin, R., O'Connor, P., & Crichton, M. (2008). Situation awareness. *Safety at the sharp end: A guide to non-technical skills*, 17-40.

Ford, E. P., Majoumerd, M. M., Randeberg, E., Aldaz, S., Reinsch, T., Wildenborg, T., & Brunner, L. G. (2017). Barrier definitions and risk assessment tools for geothermal wells. *H2020-GeoWell report*.

Gao, Z., Liu, S., & Zhang, Y. (2024). Cognitive data fusing for internet of things based on ensemble learning and federated learning. *IEEE Internet of Things Journal*, *11*(13), 22992-23001.

Geisbush, J., & Ariaratnam, S. T. (2023). Reliability centered maintenance (RCM): literature review of current industry state of practice. *Journal of Quality in Maintenance Engineering*, *29*(2), 313-337.

Gomaa, A. H. (2025). RCM 4.0: A Novel Digital Framework for Reliability-Centered Maintenance in Smart Industrial Systems. *Int. J. Emerg. Sci. Eng*, *13*, 32-43.

Hollnagel, E. (2014). Resilience engineering and the built environment. Building Research & Information, 42(2), 221-228.

Hollnagel, E. (2014). Resilience engineering and the built environment. Building Research & Information, 42(2), 221-228.

Hollnagel, E. (2017). Safety-II in practice: developing the resilience potentials. Routledge.

Hollnagel, E. (2019). Making health care resilient: from safety-I to safety-II. In *Resilient health care* (pp. 3-18). CRC Press.

Holmstrom, D., Altamirano, F., Banks, J., Joseph, G., Kaszniak, M., Mackenzie, C., ... & Wallace, S. (2006). CSB investigation of the explosions and fire at the BP Texas City refinery on March 23, 2005. *Process safety progress*, *25*(4), 345-349.

Hopkin, P. (2018). *Fundamentals of risk management: understanding, evaluating and implementing effective risk management*. Kogan Page Publishers.

Hopkins, M. (2012). Corporate social responsibility and international development: Is business the solution?. Routledge.

Isangadighi, G. E., & Udeh, J. A. (2023). Emergencies, preparedness, and management: a case study of Nigeria. *World Safety Organization*, *32*(2), 38.

Isangadighi, G. E., Mathew, P., Islam, M., Obahor, G., Offordum, A., & Momoh, P. O. (2025). Machine learning-based multivariate risk stratification framework for assessing the combined burden of occupational, infectious, and non-communicable diseases in Bagega (Zamfara) and Shiroro (Niger), Nigeria. *Journal of Clinical Practice and Medical Research*, *1*(1), 24-29.

Isangadighi, G. E., Obahor, G., Ekanem, M. E., Judith, U. O., Paul, C. J., Adedamola, S. B., & Ozohili, L. I. (2024). Machine learning-based prediction of bioaccumulation and ecotoxicity of emerging contaminants in aquatic ecosystems. *Journal of Systematic, Evaluation and Diversity Engineering*.

Isangadighi, G., & Ukudo, B. (2025). Perceptions and Awareness of Air Quality and Its Health Impacts in Agbarho Community, Ughelli North, Delta State. *Journal of African Innovation and Advanced Studies*.

Khan, F. I., & Haddara, M. R. (2004). Risk-based maintenance of ethylene oxide production facilities. *Journal of hazardous materials*, *108*(3), 147-159.

Khan, M. A. U. Z., Rahman, M. S., & Hasan, M. K. (2024). Machine Learning Approaches to Real-Time Risk Assessment in Cloud Computing: An Intelligent Framework for Proactive Threat Detection. *European Journal of Applied Science, Engineering and Technology*, *2*(4), 144-160.

Khan, S. A. R., Zia-ul-haq, H. M., Umar, M., & Yu, Z. (2021). Digital technology and circular economy practices: An strategy to improve organizational performance. Business Strategy & Development, 4(4), 482-490.

Khan, Z., Pervez, Z., & Abbasi, A. G. (2017). Towards a secure service provisioning framework in a smart city environment. *Future Generation Computer Systems*, *77*, 112-135.

Krasnopevtseva, N. J. (2022). *Challenges of developing leadership for safety in high-risk industries: an organizational approach. The case of the nuclear sector* (Doctoral dissertation, Université Côte d'Azur).

Leva, S., Dolara, A., Grimaccia, F., Mussetta, M., & Ogliari, E. (2017). Analysis and validation of 24 hours ahead neural network forecasting of photovoltaic output power. *Mathematics and computers in simulation*, *131*, 88-100.

Leveson, N. (2020). Safety III: A systems approach to safety and resilience. *MIT Eng. Syst. Lab*, *16*, 2021.

Leveson, N. G. (2011). Applying systems thinking to analyze and learn from events. Safety science, 49(1), 55-64.

Leveson, N. G. (2011). Applying systems thinking to analyze and learn from events. Safety science, 49(1), 55-64.

Leveson, N., Dulac, N., Marais, K., & Carroll, J. (2009). Moving beyond normal accidents and high reliability organizations: A systems approach to safety in complex systems. *Organization studies*, *30*(2-3), 227-249.

Moubray, J. (1997), Reliability – centered maintenance, 2nd ed., ButterworthHeinemann, Oxford, UK

Moubray, J. (2001). *Reliability-centered maintenance*. Industrial Press Inc..

Nowlan, F. S., & Heap, H. F. (1978). Reliability-centered maintenance.

O'Connor, P., Hahn, R. G., Nullmeyer, R., & Montijo, G. (2019). The military perspective. In *Crew resource management* (pp. 515-538). Academic Press.

Omwenke, I. W., Itu, P. C. O., Bassey, B. O., Effanga, B. O., Petters, E. S., Isangadighi, G. E., & Alhassan, A. (2026). Multilevel Determinants of Adverse Maternal–Fetal Outcomes in Resource-Constrained Settings: An Integrated Obstetric and Health Systems Analysis from Nigeria. *European Journal of Medical and Health Research*, *4*(1), 75-85.

Orhuebor, E. N., Chinedu, N. B., Isangadighi, G. E., Ofoegbu, C. J., Essien, U. B., & Damilola, T. E. (2026). Machine Learning-Driven Predictive Modelling of Toxic Hydrocarbon Emissions and Public Health Risks in The Port Harcourt Refining Corridor: Integrating Data Governance, Ethical AI, and Intellectual Property Protection Frameworks. *European Journal of Applied Science, Engineering and Technology*, *4*(1), 60-72.

Orhuebor, E. N., Chinedu, N. B., Isangadighi, G. E., Udeh, J. A., Uchenna, O. A., Isangadighi, G. E., & John, A. M. (2026). Occupational Health Risk Mapping in the Niger Delta Oil and Gas Fields using Machine Learning and Environmental Exposure Indices. *European Journal of Innovative Studies and Sustainability*, *2*(1), 54-71.

Orhuebor, E. N., Isangadighi, G. E., Akpololohor, C. A., & Akinboboye, R. (2025). Data-driven techno-economic and environmental assessment of compressed natural gas (CNG) vehicles as a source of transportation in Nigeria. *European Journal of Applied Science, Engineering and Technology*, *3*(5), 142-152.

Paté-Cornell, M. E. (1993). Learning from the piper alpha accident: A postmortem analysis of technical and organizational factors. *Risk analysis*, *13*(2), 215-232.

Patriarca, C., Balderrama, A., Može, M., Sjöberg, P. J., Bergquist, J., Tranvik, L. J., & Hawkes, J. A. (2020). Investigating the ionization of dissolved organic matter by electrospray. *Analytical chemistry*, *92*(20), 14210-14218.

Perrow, C. (2011). Normal accidents: Living with high risk technologies-Updated edition.

Qureshi, I., Pan, S. L., & Zheng, Y. (2021). Digital social innovation: An overview and research framework. *Information Systems Journal*, *31*(5).

Qureshi, U. U. R., Khan, M. I., & Hu, B. (2023). Realizing efficient THz circular dichroism using ultra-thin chiral metasurface. *Physica Scripta*, *98*(7), 075513.

Rashid, T. U., Kabir, S. F., Biswas, M. C., & Bhuiyan, M. R. (2020). Sustainable wastewater treatment via dye–surfactant interaction: a critical review. *Industrial & Engineering Chemistry Research*, *59*(21), 9719-9745.

Rasmussen, J. (1997). Risk management in a dynamic society: a modelling problem. Safety science, 27(2-3), 183-213.

Reason, J. (1990). *Human error*. Cambridge university press.

Reason, J. (2017). *The human contribution: unsafe acts, accidents and heroic recoveries*. CRC press.

Reason, P. (1997, August). Revisioning inquiry for action: A participatory view. Paper presented at the American Academy of Management, Boston, MA.

Salmon, B., Papovich, C., Long, J., Willner, S. P., Finkelstein, S. L., Ferguson, H. C., ... & Pforr, J. (2016). Breaking the curve with CANDELS: a Bayesian approach to reveal the non-universality of the dust-attenuation law at high redshift. *The Astrophysical Journal*, *827*(1), 20.

Salmon, P. M., Hulme, A., Walker, G. H., Waterson, P., Berber, E., & Stanton, N. A. (2020). The big picture on accident causation: A review, synthesis and meta-analysis of AcciMap studies. *Safety science*, *126*, 104650.

Santos, A. C., Willumsen, J., Meheus, F., Ilbawi, A., & Bull, F. C. (2023). The cost of inaction on physical inactivity to public health-care systems: a population-attributable fraction analysis. *The Lancet Global Health*, *11*(1), e32-e39.

Senge, P. M. (2006). *The fifth discipline: The art and practice of the learning organization*. Broadway Business.

Smith, A. M., & Hinchcliffe, G. R. (2004). 1-world class maintenance (WCM)—Opportunity and challenge,". *RCM, AM Smith and GR Hinchcliffe, Eds. Burlington: Butterworth Heinemann*, 1-18.

Thomas, J., Noel-Storr, A., Marshall, I., Wallace, B., McDonald, S., Mavergames, C., ... & Pearson, L. (2017). Living systematic reviews: 2. Combining human and machine effort. *Journal of clinical epidemiology*, *91*, 31-37.

Weick, K.E., and K.M. Sutcliffe. 2007. *Managing the unexpected: Resilient performance in an age of uncertainty*, 2nd ed. San Francisco: Jossey-Bass.

Woods, D. D. (2015). Four concepts for resilience and the implications for the future of resilience engineering. *Reliability engineering & system safety*, *141*, 5-9.

Zhu, L., Yu, F. R., Wang, Y., Ning, B., & Tang, T. (2018). Big data analytics in intelligent transportation systems: A survey. *IEEE transactions on intelligent transportation systems*, *20*(1), 383-398.