Digital Technologies in Occupational Health and Safety Management in Nigeria's Upstream Offshore Oil and Gas Sector: A Critical Review of Gap-Bridging Potential

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ABSTRACT

The accelerating proliferation of digital technologies presents unprecedented opportunities to address the systemic implementation gaps that have long characterised occupational health and safety (OHS) management within Nigeria's upstream oil and gas sector. Building on a foundational study that identified six critical barriers—including production-priority conflicts, resource inadequacy, regulatory enforcement deficits, and the invisibility of cumulative occupational exposures—this paper examines the gap-bridging potential of real-time risk platforms and artificial intelligence (AI)-assisted hazard identification systems in overcoming these entrenched challenges. Drawing on a critical, non-systematic review of recent empirical literature and industry deployment evidence, the study applies a Technology Acceptance Model (TAM) and Diffusion of Innovation (DOI) theoretical lens to evaluate how digital solutions interact with organisational, regulatory, and human factors in high-hazard offshore environments. The evidence synthesis indicates that AI-enabled predictive safeguards, IoT-integrated monitoring architectures, and data-driven decision-support platforms *are theoretically and empirically positioned to address* the production-priority override, resource inadequacy, and chronic exposure invisibility barriers—the three most pervasive implementation failures documented in the sector—while offering the potential to transform occupational health surveillance from reactive to continuous and predictive. However, significant contextual barriers—including legacy infrastructure constraints, cybersecurity vulnerabilities, workforce digital literacy deficits, ethical and privacy considerations, and cost-prohibitive adoption thresholds—continue to moderate uptake in the Nigerian context. The paper concludes with a strategic framework for staged digital integration and targeted policy recommendations for the Nigerian Upstream Petroleum Regulatory Commission (NUPRC) and industry operators seeking to operationalise technology-enabled safety governance.

Keywords: artificial intelligence; hazard identification; real-time risk platforms; occupational health and safety; Niger Delta offshore; offshore oil and gas; digital transformation; implementation gaps; HSE management; critical review

INTRODUCTION

This paper focuses specifically on offshore upstream operations in the Niger Delta region of Nigeria, which hosts the majority of the nation's offshore infrastructure. Nigeria's upstream oil and gas industry operates within one of the world's most hazardous occupational environments, where extreme physical conditions, complex chemical exposures, and a persistent tension between production imperatives and safety compliance have produced a record of recurring incidents—including gas leaks, equipment failures, oil spills, and occupational health crises—that expose the fundamental inadequacy of prevailing safety management architectures across this sector [1,2]. Onshore upstream facilities, while sharing many structural challenges, present a distinct regulatory and infrastructural context beyond the boundaries of this review. The offshore context is particularly demanding: as documented by Vinnem [3], the combination of process hazards, structural complexity, and human factors in offshore installations generates risk profiles that substantially exceed those of onshore equivalents.

A foundational study directly informing the present work surveyed 300 industry professionals and applied risk matrix analysis to classify prevalent hazards, finding that while organisations nominally adhere to safety standards, substantive compliance gaps persist across environmental risk assessment, emergency preparedness, and the early detection of chronic occupational exposures, with ageing infrastructure, inadequate maintenance, and inconsistent regulatory enforcement identified as the most persistent structural risks undermining worker protection [2]. Parallel investigation into the policy environment documented six discrete implementation barriers: production-pressure override affecting 78% of workers; resource inadequacy reported by 89% of managers; enforcement weakness acknowledged by 94% of regulators; contractor accountability ambiguity cited by 83% of health professionals; knowledge-to-practice gaps experienced by 84% of workers; and the clinical invisibility of gradually accumulating occupational diseases noted by 91% of all participants. These findings point not to a failure of regulation per se, but to a systemic failure of implementation that no conventional compliance-based intervention has yet fully resolved in the documented study context [4].

Against this backdrop, this paper asks: can digital technologies—specifically real-time risk monitoring platforms and AI-assisted hazard identification systems—serve as structural interventions capable of disrupting these entrenched implementation failures? To address this question, the paper synthesises recent empirical research on AI and IoT applications in offshore safety management, evaluates documented deployment outcomes, and situates findings within the organisational and regulatory context of the Nigerian oil and gas sector [5][6][7]. The ultimate objective is not merely to catalogue emerging technologies but to critically assess their translational potential and outline the conditions under which their deployment could produce measurable, lasting safety improvements.

LITERATURE REVIEW

Review Methodology

This paper is positioned as a critical, non-systematic review of the empirical and policy literature on digital OHS technologies in the Nigerian upstream oil and gas sector. Literature was identified through searches of Google Scholar, Scopus, and IEEE Xplore using search terms including “occupational health and safety,” “Nigeria oil and gas,” “real-time risk platforms,” “AI hazard identification,” “Industry 4.0 offshore safety,” and “digital transformation HSE.” Coverage was limited to English-language publications, with a primary focus on material from 2014 to 2026. The rationale for the English-language restriction reflects practical resource constraints, and the authors acknowledge that relevant research may exist in Portuguese (Angola, Mozambique) and other languages—a limitation discussed further in §7.1.

The initial search retrieved approximately 140 records across the three databases. Records were screened at title and abstract level against the following inclusion criteria: (a) relevance to OHS management in the oil and gas sector or an analogous high-hazard industrial context; (b) direct engagement with digital technologies, AI, IoT, or related Industry 4.0 tools in safety or hazard management; (c) relevance to the Nigerian offshore context or documented transferability to comparable legacy-infrastructure environments; and (d) publication in a peer-reviewed outlet or, where peer-reviewed equivalents were unavailable, in identifiable grey literature outlets explicitly labelled as such. Records were excluded where they addressed exclusively downstream or refining operations, were duplicates, or were inaccessible in full text. Following screening, 25 sources met the inclusion criteria and are included in this review.

Prior Literature on Nigerian OHS Implementation Gaps

The literature on occupational health and safety in Nigerian industries consistently identifies a disjunction between formal policy frameworks and operational realities, a pattern that is particularly pronounced in the upstream oil and gas sector [5,6,7]. Ali and Misnan [2] documented that despite comprehensive safety regulations, companies in the Nigerian upstream sector demonstrate persistent inconsistencies in risk assessment practice—particularly in environmental hazard evaluation and emergency scenario planning—with oil spills, gas leaks, and structural failures classified as high-frequency, high-severity risks whose preparedness indices remained disproportionately low relative to their documented probability.

This gap between hazard knowledge and operational readiness reflects a well-documented limitation of reactive safety management—one that focuses on incident response rather than systemic foresight and that by definition cannot address risks that have not yet produced visible failures. Hollnagel [8] characterises this as the Safety-I paradigm, in contrast to the Safety-II approach that seeks to understand and amplify what goes right rather than merely responding to what goes wrong. The Safety-I/Safety-II distinction is analytically relevant here because digital technologies offer precisely the kind of prospective, systems-level awareness that Safety-II prescribes, while Safety-I reactive cultures remain a documented barrier to their adoption.

Ogbonna and Iwuanyanwu [4] offered the most granular account of implementation failure through a mixed-methods design involving 412 workers and 54 stakeholder interviews. Multivariate analysis established that effective safety policies, when genuinely implemented, reduce chronic occupational disease incidence by 38%—the inverse being that their systematic non-implementation leaves workers unprotected despite formal regulatory coverage. Their identification of gradually developing diseases—musculoskeletal disorders at 68%, hearing loss at 53%, and respiratory conditions at 41%, all far exceeding population norms—underscores the inadequacy of the sector's reactive monitoring approach, which captures acute incidents far more readily than the slow accretion of occupational harm.

The availability and distribution of Occupational Safety, Health and Environment (OSHE) professionals further contextualises these gaps. Olorunlogbon et al. [9] confirmed a statistically significant positive association ($p < 0.05$) between the effective presence of OSHE professionals and improved safety outcomes across subsectors—yet also revealed the structural asymmetry at the heart of the crisis: organisations with strong OSHE teams perform markedly better, but the supply of such specialists remains unevenly distributed across remote and offshore locations. This personnel gap cannot be closed without either growing specialist capacity or deploying technological substitutes capable of performing continuous hazard surveillance.

Digital Technologies in Offshore Safety: Global Evidence

Recent offshore safety literature reflects a gradual shift from periodic, inspection-based safety management toward data-intensive, predictive, and continuously monitored risk control. Within this development, three technology clusters are most relevant to offshore OHS: AI-enabled predictive safeguards, AIoT-based real-time monitoring, and AI-driven HSE systems integrating computer vision, sensor networks, and decision-support analytics [5–7, 10]. These technologies are significant because they can improve hazard visibility, generate earlier warnings, and support more consistent translation of risk information into operational decisions. However, the evidence base remains uneven, with stronger support for technical feasibility and operational performance than for direct worker-health and safety outcomes.

Aderamo et al. [5] provide a framework for AI-enabled predictive safeguards in offshore facilities, emphasising machine-learning-based anomaly detection, sensor integration, and early warning for safety-critical assets. A related study by the same research team [7] extends this argument to AI-driven HSE management systems incorporating computer vision, predictive analytics, and multi-sensor IoT data streams. Together, these studies support the conceptual and technical case for predictive digital safety management, but their findings should be interpreted cautiously: they establish plausible mechanisms rather than definitive evidence of reduced injury, illness, or fatality rates in the Nigerian offshore context.

Adejumo et al. [6] offer more locally relevant evidence through their examination of AIoT applications for real-time monitoring and predictive maintenance on offshore platforms, particularly Electrical Submersible Pump systems. This study is useful because it demonstrates the feasibility of continuous sensor-based monitoring in operating conditions relevant to Nigeria. Nevertheless, its reported benefits relate primarily to equipment reliability, reduced downtime, and asset-life extension rather than direct OHS outcomes. Its relevance to worker safety is therefore indirect and should be treated as evidence of monitoring capability rather than proof of OHS effectiveness.

Commercial computer-vision applications, such as the viAct deployment example reported in trade press [11], illustrate how AI video analytics may support PPE monitoring, hazardous-zone control, and real-time alerting. Because this source is not peer-reviewed, it should be cited only as illustrative evidence of emerging practice. Overall, the global evidence supports cautious optimism: digital offshore safety technologies have credible gap-bridging potential, but their Nigerian value will depend on infrastructure readiness, workforce acceptance, cybersecurity, privacy governance, cost feasibility, and phased implementation. From a TAM-DOI perspective, adoption will depend not only on perceived usefulness and ease of use, but also on compatibility, trialability, observability, and demonstrable safety benefit in Nigerian offshore settings.

Industry 4.0 and the Digital Transformation of the Oil and Gas Sector

The broader digital transformation literature frames these technological deployments within the Industry 4.0 paradigm, which integrates IoT, AI, digital twins, cloud analytics, and automation into unified operational architectures. Lu [13] provides a systematic peer-reviewed overview of Industry 4.0 technologies, applications, and open research issues that grounds the framework description adopted here. Ramasamy [12] articulates an integrated transformation framework for offshore and modular assets combining Industry 4.0 enablers with Industry 5.0 human-centric themes via open API-driven modular platforms—an approach relevant to the Nigerian context where legacy infrastructure heterogeneity demands interoperable, modular digital solutions rather than monolithic platform replacements. Given the grey-literature status of this source, the substantive framing of this paper draws primarily on Lu [13] and equivalent peer-reviewed sources; Ramasamy [12] is retained as illustrative context only.

Among the most significant Industry 4.0 enablers in the safety domain is the digital twin—a continuously updated virtual replica of physical assets and processes through which operational scenarios and risk conditions can be simulated before physical intervention [14]. The regulatory dimension of this transformation is addressed by the Nigerian Upstream Petroleum Regulatory Commission (NUPRC), whose Health, Safety, Environment and Community (HSEC) Department has articulated explicit mandates for Process Safety management and Safety Standards Development [15]. It should be noted, however, that NUPRC's specific enforcement mechanisms and documented shortfalls in implementation capacity represent a significant analytical gap in the regulatory literature, warranting more critical interrogation than a single mandate citation can provide—a tension addressed in Section VI.

Theoretical Framework

This study is grounded in two complementary theoretical frameworks that collectively explain both the adoption dynamics of digital safety technologies and their organisational integration pathways. The Technology Acceptance Model (TAM), originally developed by Davis [16] (1989) and subsequently adapted to industrial settings, posits that perceived usefulness and perceived ease of use are the primary determinants of technology adoption intention. The authors acknowledge that significant extensions of the TAM framework have been developed since its original formulation, including TAM2, TAM3, and the Unified Theory of Acceptance and Use of Technology (UTAUT), which incorporate additional determinants such as social influence, facilitating conditions, and experience. For the purposes of this critical review, the original TAM formulation is considered sufficient as a conceptual mapping lens; future empirical research should engage with more recent TAM adaptations specific to industrial AI-mediated contexts and safety-critical regulatory environments.

Applied to real-time risk platforms and AI-assisted hazard identification systems in the Nigerian offshore context, TAM generates the following proposition:

Proposition 1: Adoption of digital OHS technologies in the Nigerian offshore sector will be significantly moderated by workforce digital literacy, management confidence in algorithmic risk outputs, and the transparency of AI decision-making processes. A hypothesis for future empirical investigation is that perceived ease of use will prove to be the binding adoption constraint, given the documented knowledge-to-practice gaps [4] and digital literacy deficits among Nigerian oil and gas workers; however, this remains to be empirically tested and should not be treated as an established finding within the present review. Substantive investment in interface design and workforce training is predicted as a prerequisite before platforms can realise their full safety potential.

The TAM framework also foregrounds the role of organisational culture. Where the prevailing paradigm remains reactive—investigating failures after they occur rather than anticipating and preventing them [8]—digital tools that generate prospective alerts may be experienced as sources of operational disruption rather than safety value. This is consistent with the Safety-I/Safety-II distinction outlined in §2.1: digital OHS technologies are fundamentally Safety-II instruments, and their deployment into Safety-I organisational cultures creates a specific mechanism by which culture mediates perceived usefulness and suppresses adoption. Making cultural readiness an explicit precondition for deployment is therefore analytically warranted.

Rogers' Diffusion of Innovations (DOI) theory [17] provides the second analytical lens, conceptualising the spread of technological innovations through social systems as a function of relative advantage, compatibility, complexity, trialability, and observability. This generates a second proposition:

Proposition 2: The relative advantage of digital safety platforms over existing manual and paper-based systems is demonstrable in their capacity to provide continuous monitoring at scale [7]—a capability that conventional periodic inspection cannot match. Compatibility with existing regulatory frameworks is, however, less assured given the documented misalignment between NUPRC standards and their operational implementation [15]. Complexity and cost considerations[5,6] are predicted to retard diffusion unless supported by coordinated industry or regulatory incentives.

The integration of TAM and DOI perspectives generates a multi-level analytical framework that examines digital safety technology adoption simultaneously at the individual (user), organisational, and systemic (regulatory/industry) levels—a scope that matches the multi-layered nature of OHS implementation gaps in the sector. The two frameworks converge in predicting that adoption will be constrained by digital literacy deficits and cost barriers; they diverge in that DOI's trialability and observability constructs have no direct TAM equivalent but are equally relevant to the Nigerian offshore adoption context. It is acknowledged that alternative frameworks—including Sociotechnical Systems Theory (STS), Work System Theory, and the Technology-Organisation-Environment (TOE) model—offer complementary analytical lenses that future research could productively apply to this domain.

Digital Technologies: Mechanisms And Gap-Bridging Potential

Real-Time Risk Platforms

Real-time risk platforms (RTRPs) constitute a class of integrated technological systems that aggregate continuous data streams from sensors, wearables, environmental monitors, and process control systems to generate dynamic, continuously updated risk assessments. They replace periodic static evaluations—susceptible to obsolescence between review cycles—with situational awareness that brings the temporal granularity of safety monitoring into alignment with the pace at which hazards actually evolve in complex industrial environments.

RTRPs are theoretically positioned to counteract the production-priority override problem by generating objective, timestamped risk data that creates an auditable accountability record—one that supervisors or managers cannot dismiss without formal documentation. Where safety concerns were previously mediated by hierarchical human decision-making susceptible to production pressure, RTRPs introduce an automated alert pathway that reduces dependence on informal override dynamics. This mechanism is largely inferred from the design properties of these systems; while Adejumo et al. [6] demonstrated that AIoT monitoring systems trigger maintenance interventions based on sensor thresholds independent of operational scheduling pressures, the specific accountability-enforcement function against production-priority override has not been directly documented in the Nigerian offshore context and should be treated as a theoretical proposition pending empirical investigation.

RTRPs also address the resource inadequacy barrier by enabling lean safety monitoring: a small safety team augmented by automated surveillance achieves coverage equivalent to a much larger manual inspection force, with cost-per-unit-of-monitoring-coverage ratios that increasingly favour digital platforms as operational scale increases [5]. Critically for the Nigerian context, RTRPs generate the rich, structured operational safety data that substantively fulfils NUPRC's mandate for systematic safety audits and incident investigation [15], allowing platform-generated reports to reduce the enforcement burden on acknowledged under-resourced regulatory inspectors and thereby addressing the regulatory enforcement deficit through data infrastructure rather than personnel expansion.

AI-Assisted Hazard Identification

AI-assisted hazard identification (AIHI) systems represent perhaps the most consequential digital innovation for addressing the OHS implementation gaps identified in the foundational studies [5,7]. Their capacity to detect patterns imperceptible to human observation—whether in sensor data streams, visual surveillance footage, or operational parameter histories—directly targets the clinical invisibility of cumulative occupational exposures. In analogous industrial settings, AI pattern-recognition systems have been shown to identify precursor signatures of mechanical failure in sensor data long before human assessment would flag a risk; comparable applications to occupational exposure monitoring represent a significant avenue for future deployment.

Aderamo et al. [5] demonstrated that machine learning models trained on historical offshore operational data can identify precursors to equipment failure with sufficient specificity to generate actionable early warnings—a predictive capability analytically distinct from conventional risk assessment, since AIHI systems identify emerging risk signatures that human assessors may not have previously recognised as significant. In the Nigerian context, where risk matrices accurately classify hazards but preparedness remains disproportionately low [2], AIHI offers a mechanism to translate hazard knowledge directly into operational alerts, closing the knowledge-to-practice gap at the point of identification rather than relying on managerial discretion.

Computer vision applications represent a particularly powerful AIHI deployment for offshore environments. viAct's documented deployments [11] demonstrated real-time monitoring of PPE compliance, detection of unsafe worker behaviours, and identification of unauthorised zone intrusions during shift handovers. Aderamo et al. [7] further demonstrate that AI-driven HSE management systems integrating computer vision, predictive analytics, and multi-sensor IoT data streams can create comprehensive, dynamic risk pictures while automating routine safety checks.

For musculoskeletal, audiological, and respiratory conditions that accumulate over careers but remain invisible until clinically manifest [4], AIHI systems integrated with wearable health monitoring devices may theoretically offer continuous physiological and environmental monitoring that could establish personal exposure baselines, identify deviations, and trigger intervention thresholds before clinical symptoms emerge. *This mechanism is theoretically inferred from the general wearable health monitoring literature and has not been directly validated in the Nigerian offshore context; it should be regarded as a hypothesis for future empirical investigation rather than an established capability in this setting.* If realised, this would transform occupational health surveillance from reactive and periodic to continuous and predictive.

Table 1: Digital Technology × Implementation Gap-Bridging Matrix

Implementation Barrier	RTRP Mechanism	AIHI Mechanism	Evidence	Evidence Strength
Production-priority override	Automated, timestamped alerts create auditable accountability records that require formal documentation to	AI-flagged risk data reduces reliance on supervisor discretion for safety responses	[5, 6]	Inferential — mechanism inferred from system design properties; no Nigerian-context study directly documents the accountability-enforcement

	override			function
Resource inadequacy	Lean monitoring extends specialist coverage at scale; reduces cost-per-unit of surveillance	Automated checks reduce manual inspection burden	[5, 7]	Moderate — global peer-reviewed studies in analogous offshore contexts; Nigeria-specific empirical validation required
Regulatory enforcement deficit	Platform-generated data fulfils NUPRC audit and reporting requirements	AI compliance monitoring supports regulatory oversight	[6, 15]	Moderate — Nigerian-context [6] focuses on operational efficiency; [15] is regulatory documentation; direct enforcement-relief evidence is inferential
Contractor accountability ambiguity	Real-time zone monitoring tracks contractor activities with timestamped logs	Computer vision flags unauthorised zone entries	[11]†	Inferential — sole source is trade press [11]; peer-reviewed corroboration required
Knowledge-to-practice gap	Sensor thresholds trigger maintenance interventions automatically, bypassing knowledge-application delay	AIHI translates hazard data directly into operational alerts at the point of identification	[5, 6]	Moderate — supported by peer-reviewed studies; primary evidence in [6] relates to equipment operations, not direct safety practice
Clinical invisibility of cumulative exposure	Continuous wearable physiological monitoring establishes exposure baselines and tracks deviations	Exposure threshold alerts theoretically possible before clinical symptom onset	[4, 5, 7]	Inferential — wearable AIHI integration mechanism is theoretically inferred from general health monitoring literature; not empirically validated in Nigerian offshore context

† [11] is trade press; evidence requires peer-reviewed corroboration. Evidence strength levels: Strong = Nigerian-context peer-reviewed empirical study directly supporting mechanism claim; Moderate = global peer-reviewed study with documented applicability to analogous offshore contexts; Inferential = mechanism derived from technology design properties, grey literature, or extrapolation without direct empirical support. Evidence strength varies by row; strongest where Nigerian-context empirical studies are cited.

The gap-bridging mechanisms described in Sections 4.1 and 4.2 represent what real-time risk platforms and AI-assisted hazard identification systems are theoretically and empirically positioned to achieve under favourable deployment conditions. However, the realisation of these mechanisms in the Nigerian offshore context is not automatic; it is contingent on a set of structural, organisational, and contextual conditions. The evidence synthesis presented above should therefore be read not as an assertion that digital technologies will automatically close the documented implementation gaps, but as a structured mapping of the pathways through which they *could* do so—pathways that contextual barriers in the Nigerian setting may substantially narrow or block. The relationship between technological capability and operational safety outcome is, in this context, co-determined by infrastructure adequacy, regulatory alignment, workforce capacity, and organisational culture. Section V examines each of these moderating factors in turn.

Challenges And Contextual Limitations

Infrastructure and Connectivity

The deployment of real-time risk platforms and AI-assisted hazard identification systems in the Nigerian offshore context encounters immediate infrastructure constraints. Platforms in the Niger Delta are reported by industry sources to operate with communications infrastructure ranging from high-bandwidth satellite connectivity at major installations to intermittent signal availability at marginal assets (this characterisation is based on industry-reported conditions; peer-reviewed technical studies or official infrastructure assessments are required to corroborate it). Cloud-based AI processing—which underpins many state-of-the-art safety platforms—requires reliable, low-latency data transmission that cannot be guaranteed across the sector's infrastructure diversity. While edge computing architectures that process data locally on the platform before selective cloud transmission offer a viable partial mitigation, they require additional hardware investment and maintenance capacity that is not readily available across the sector, effectively creating a two-tier adoption landscape in which the most sophisticated digital safety tools are accessible only to operators with the most developed communications assets.

Legacy Systems Integration

The majority of Nigeria's offshore production infrastructure predates the digital transformation era, and sensor retrofitting, data protocol standardisation, and the integration of legacy SCADA systems with modern AI platforms present significant technical and financial challenges. Peer-reviewed literature on industrial IoT and Industry 4.0 systems integration [13] identifies legacy integration as a primary obstacle to digital adoption in complex industrial environments—a conclusion consistent with the Nigerian offshore context. Ramasamy [12] (grey literature; cited for illustrative context only) discusses open API-driven architectural approaches as a response to legacy heterogeneity; peer-reviewed industrial systems integration literature should be consulted to substantiate claims in this area. These integration challenges require specialist digital engineering capability that is presently scarce in the Nigerian market, meaning that legacy integration is simultaneously a technical problem and a skills pipeline problem, both of which must be addressed for digital safety technology deployment to reach its potential.

Cybersecurity Risks

The digitisation of safety-critical systems introduces cybersecurity vulnerabilities that must be systematically addressed before deployment. Aderamo et al. [5] explicitly note that a successful cyberattack on an integrated safety platform could disable protective mechanisms across an entire facility simultaneously—a risk profile qualitatively different from the failure modes of conventional safety systems, where failures tend to be localised and physical rather than systemic and digital. Industrial control systems in the oil and gas sector face a threat landscape that includes opportunistic ransomware and targeted attacks, risks extensively documented in operational technology (OT) security literature [18]. Established guidance frameworks—specifically the NIST Guide to Industrial Control Systems Security [18]—identify network segmentation, authentication controls, and continuous monitoring as foundational mitigations for OT environments.

It should be noted that no documented cybersecurity incidents specifically targeting Nigerian oil and gas operational technology systems were identified within the scope of this review; the risk characterisation presented here is therefore based on global OT security evidence, extrapolated to the Nigerian context on the basis of the sector's digital connectivity characteristics. Nigerian operators face the dual challenge of deploying technologies capable of improving safety while ensuring those same technologies do not introduce new, potentially catastrophic vulnerabilities into facilities already operating under significant risk pressure.

Workforce Digital Literacy and Change Resistance

The effectiveness of digital safety technologies is ultimately contingent on human interaction with them. Workers who do not trust, understand, or know how to use AI-generated safety alerts effectively will not respond to them appropriately—a point sharpened by the knowledge-to-practice gap [4] already documented in the sector, which implies that the gap between knowing what is safe and doing what is safe may be compounded, rather than resolved, by technologies that add a layer of digital interpretation between the worker and the hazard. Research on human error in complex sociotechnical systems consistently demonstrates that the introduction of new technology into existing workflows can produce unforeseen failure modes if the human and organisational dimensions of adoption are not managed with at least as much rigour as the technical implementation [21][22].

In the offshore context, the non-technical skills required to effectively monitor, interpret, and act on automated safety alerts—including situation awareness, decision-making under uncertainty, and communication across hierarchical boundaries—represent a distinct competency domain that must be developed alongside technical training [20]. Organisational cultures that have historically prioritised production over safety may also resist the accountability transparency that continuous digital monitoring introduces, particularly where AI-generated alerts create auditable records of supervisory responses.

Cost and Accessibility

The financial threshold for deploying enterprise-grade real-time risk platforms and AI safety systems remains prohibitive for smaller operators and marginal asset portfolios. While the business case for safety investment—measured against the costs of incidents, regulatory penalties, and productivity losses—is demonstrably positive at scale [7], short-term capital allocation pressures in a sector subject to oil price volatility mean that returns on safety investment are realised over horizons that frequently extend beyond the planning cycles of operators under financial stress. This structural barrier to adoption suggests a necessary role for regulatory mandates, tax incentives, or consortium-based procurement models to ensure that digital safety technology adoption extends beyond the largest and most financially resilient operators in the sector.

Ethical and Privacy Considerations

Continuous digital monitoring of workers via wearables, computer vision, and biometric sensors raises significant ethical, legal, and social implications that, in the authors' assessment, the OHS digitalisation literature has given insufficient attention to. Data generated by these systems—including physiological readings, location data, and behavioural patterns—is sensitive and subject to the provisions of Nigeria's National Data Protection Regulation (NDPR) 2019, which establishes consent requirements, data minimisation principles, and obligations for data subjects' rights [23]. Industry operators must determine what data is collected, for what purposes, how long it is retained, who has access to it, and how workers are informed and can contest its use [23]. The International Labour Organization (ILO) framework on the protection of workers' personal data provides additional normative guidance on worker dignity, privacy, data collection, storage, security, and permissible use of employee information, which should be integrated into digital monitoring deployment protocols [24,25].

The use of AI-generated monitoring data in disciplinary or performance management decisions—as opposed to strictly safety-protective purposes—must be governed by transparent, negotiated protocols that distinguish safety-oriented data use from managerial surveillance [24,25]. These considerations are not peripheral compliance obligations; they are substantive determinants of workforce trust in digital safety systems and therefore of adoption success. Failure to address privacy concerns proactively risks producing worker resistance and non-compliance that could undermine the safety benefits of even the most technically advanced OHS platforms [25].

Table 2: Contextual Challenge Severity Assessment

Challenge	**Severity (Nigerian Context)**	**Mitigation Feasibility**	**Key Evidence**
Infrastructure & Connectivity	**High**	Moderate (edge computing)	[6]

Legacy Systems Integration	**High**	Moderate (API architecture)	[13]
Cybersecurity Risks	**Critical**	Moderate (security-by-design)	[5, 20]
Workforce Digital Literacy	**High**	High (structured training)	[4, 21, 22]
Cost & Accessibility	**Critical**	Low–Moderate (incentive models)	[7]
Ethical & Privacy Concerns	**Moderate**	High (regulatory frameworks)	NDPR 2019; ILO

Severity ratings are author assessments based on synthesised evidence. Severity criteria: Critical = barrier that directly blocks safe deployment if unaddressed; High = barrier requiring substantive mitigation investment; Moderate = barrier manageable within existing regulatory and operational frameworks.

STRATEGIC RECOMMENDATIONS

Based on the foregoing analysis, this paper proposes the following strategic recommendations for policymakers, regulators, and industry operators seeking to leverage digital technologies to address OHS implementation gaps in Nigeria's upstream offshore sector.

Phased Digital Integration Framework

Industry operators should adopt a structured and risk-based approach to digital safety technology integration, prioritising high-consequence and high-frequency risk domains. Initial deployment efforts should focus on AI-assisted gas leak detection, structural integrity monitoring, and PPE compliance systems because these technologies offer clear and measurable safety benefits and are supported by relatively mature market solutions. As organisational capability matures, operators can expand implementation to include integrated AIHI systems, real-time occupational health monitoring, predictive analytics, and cross-platform data integration. Such sequencing helps manage investment costs, build internal digital capability progressively, and generate evidence of safety value that supports wider adoption. The effectiveness of digital safety technology integration should be evaluated through measurable reductions in near-miss incidents, unsafe acts, and unplanned operational disruptions relative to facility-specific baseline performance, with targets established using risk-based benchmarking and organisational safety objectives.

Regulatory Mandate and Standardisation

NUPRC should leverage its safety standards development and coordination mandate to establish minimum digital safety monitoring standards for offshore operations. Similar to the role of ISO 45001 in OHS management systems, such standards should provide guidance on technology deployment, data governance, interoperability requirements, system reliability, and reporting obligations. Promoting interoperability standards would facilitate information sharing among operators, regulators, and research institutions, thereby supporting sector-wide learning and AI model development.

Recognising existing enforcement and capacity challenges, regulatory development should be accompanied by stakeholder engagement, institutional strengthening, and collaboration with industry associations, professional bodies, and international partners to support effective implementation.

Progress should be measured by the development, adoption, and implementation of nationally recognised digital safety monitoring standards, together with increasing levels of operator compliance and interoperability across digital safety systems used within the offshore sector.

Workforce Development and Digital Literacy

Industry associations and operators should invest in structured digital literacy and competency development programmes for OSHE professionals, supervisors, and frontline personnel. Given the documented shortage of

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OSHE specialists, digital tools should be deployed to augment and extend specialist capability rather than replace human expertise. Training programmes should focus on interpreting AI-generated safety alerts, operating digital monitoring platforms, analysing safety dashboards, managing digital records, and strengthening the situation awareness and communication skills required in technology-intensive work environments.

Industry associations should play a coordinating role in curriculum development, certification, and dissemination of best practices.

Success should be assessed through improvements in workforce digital competency, demonstrated proficiency in the use of digital safety platforms, and increased utilisation of AI-enabled safety information in operational and safety-critical decision-making processes.

Cybersecurity Integration from Design

Industry operators should ensure that cybersecurity considerations are embedded in every digital safety platform from inception. This should include network segmentation, robust authentication mechanisms, access controls, encrypted communications, vulnerability assessments, and regular security testing. Operators should align digital safety implementations with recognised OT cybersecurity frameworks, including IEC 62443 and the NIST Guide to Industrial Control Systems Security.

Regulators and industry stakeholders should collaborate to develop sector-specific guidance addressing cybersecurity risks associated with safety-critical digital technologies. Security-by-design should be treated as a core safety requirement rather than an afterthought, with cybersecurity performance evaluated alongside functional safety performance prior to deployment.

Performance should be evaluated through sustained compliance with recognised operational technology cybersecurity frameworks, effective vulnerability management, and the maintenance of resilient safety-critical systems with minimal exposure to cybersecurity threats.

Table 3: Recommendation Responsibility Matrix (RACI)

Recommendation	NUPRC	Industry Operators	Industry Associations	Universities / Research
6.1 Phased Integration	C	R / A	C	I
6.2 Regulatory Standards	R / A	C	C	I
6.3 Workforce Development	I	R / A	R / C	C
6.4 Cybersecurity by Design	C / A	R	I	I

R = Responsible; A = Accountable; C = Consulted; I = Informed.

CONCLUSION

This critical review has examined the extent to which real-time risk platforms and AI-assisted hazard identification systems may help address persistent OHS implementation gaps in Nigeria's upstream offshore oil and gas sector. The synthesis suggests that these technologies are most valuable not as simple digital extensions of existing HSE procedures, but as potential enablers of more timely, visible, auditable, and predictive safety governance. Through continuous monitoring, automated alerts, structured data capture, and predictive analytics, they are theoretically and empirically positioned to support responses to production-priority override, resource inadequacy, regulatory enforcement weakness, knowledge-to-practice gaps, and the clinical invisibility of cumulative occupational exposures.

However, the evidence does not support a deterministic claim that digital technologies will automatically close these implementation gaps. The strength of support varies across the reviewed mechanisms: some claims are grounded in peer-reviewed studies, while others remain inferential, drawn from analogous offshore contexts, operational-efficiency studies, or grey-literature deployment examples. Accordingly, the contribution of digital OHS technologies in the Nigerian offshore context should be understood as conditional on infrastructure readiness, regulatory alignment, cybersecurity assurance, workforce digital literacy, data protection safeguards, and organisational commitment to safety-first decision-making.

The TAM-DOI framework reinforces this conditional interpretation. Adoption is likely to depend on perceived usefulness, perceived ease of use, compatibility with existing HSE systems, trialability, observability of benefits, and the perceived relative advantage of digital platforms over conventional inspection and reporting practices. These adoption factors are especially important in a sector where production pressure, limited specialist capacity, legacy infrastructure, and cost constraints may impede diffusion. Digital safety transformation should therefore be approached as a sociotechnical governance reform rather than a technology procurement exercise.

Overall, this review supports cautious optimism. Real-time risk platforms and AI-assisted hazard identification systems offer credible gap-bridging potential, but their effectiveness will depend on phased implementation, worker engagement, cybersecurity-by-design, ethical data governance, and empirical validation under Nigerian offshore operating conditions. The immediate policy challenge is to convert technological potential into context-specific, evidence-generating interventions that strengthen worker protection and regulatory accountability.

Limitations of the Review

This review has several limitations. First, it is a critical, non-systematic review based on secondary literature; it does not include primary empirical data, formal risk-of-bias assessment, or meta-analytic synthesis. Its conclusions should therefore be interpreted as framework-guided analytical synthesis rather than evidence of proven intervention effectiveness.

Second, the evidence base remains limited and uneven. Peer-reviewed studies directly examining AI, IoT, or real-time risk systems in Nigeria's offshore OHS context are still scarce, and some technology-related claims rely on analogous contexts, operational-performance studies, or grey literature. Such sources are useful for identifying emerging practice but carry lower evidential weight and require empirical corroboration before being used as a basis for regulatory or investment decisions.

Finally, the field of digital OHS is rapidly evolving. Evidence on AI performance, cybersecurity risk, data governance, worker acceptance, and cost-effectiveness may change as deployment experience increases. The conclusions of this review should therefore be treated as a current synthesis and agenda-setting contribution rather than a final assessment of digital OHS effectiveness in the Nigerian offshore sector.

Future Research Priorities

Future research should prioritise empirical validation of digital OHS technologies in Nigerian offshore settings. Longitudinal facility-level studies are needed to assess safety outcomes before and after deployment of real-time risk platforms or AI-assisted hazard identification systems, using both lagging indicators such as Total Recordable Incident Rate, occupational illness reports, incident severity, lost-time injuries, and leading indicators such as near-miss quality, alert-response time, corrective-action closure, exposure-threshold exceedance, and safety-critical maintenance compliance.

Additionally, long-term occupational health outcomes should become a central research priority. Studies are needed to determine whether wearable sensors, exposure monitoring, and AI-assisted analytics can support earlier detection of cumulative musculoskeletal, respiratory, audiological, chemical, and fatigue-related risks. Cost-effectiveness and return-on-investment research should also be conducted, especially for smaller operators and marginal asset portfolios, to determine whether digital OHS adoption can be scaled equitably across the sector

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