INTERNATIONAL JOURNAL OF LATEST TECHNOLOGY IN ENGINEERING, MANAGEMENT & APPLIED SCIENCE (IJLTEMAS)

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VIII, August 2026

Risk Assessment and Management Tool Use, Implementation Quality and Perceived Effectiveness During Shutdown and Turnaround Maintenance: Evidence from a Nigerian Upstream Petroleum Operator

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DOI: https://doi.org/10.51583/IJLTEMAS.2026.150800055

Received: 26 August 2026; Accepted: 31 August 2026; Published: 10 September 2026

ABSTRACT

Risk assessment and management (RAM) tools are central to shutdown and turnaround maintenance (STAM), but frequent use does not necessarily demonstrate implementation quality or safety effectiveness. This cross-sectional study analysed respondent-level survey data from 148 STAM professionals in a Nigerian upstream petroleum organisation. Descriptive statistics, Spearman correlations, exploratory factor analysis (EFA), robust multiple regression and Mann-Whitney U incident-group comparisons were applied. JSA ($M = 4.53$) and toolbox talks ($M = 4.35$) were used more frequently than HAZOP ($M = 2.30$) and risk registers ($M = 2.27$). EFA showed only marginal sampling adequacy (KMO = .610; Bartlett's chi-square(10) = 54.70, $p < .001$) and a weak two-factor structure, confirming that C1-C5 should not be treated as a strongly unidimensional effectiveness scale. The regression model explained little variance in the composite score ($R2 = .031$; adjusted $R2 = -.018$; robust $F = 0.62$, $p = .741$), and no predictor was significant. Incident-experienced respondents reported modestly higher JSA use, incident-prevention perceptions and field-implementation perceptions, but the composite effectiveness difference was non-significant. The findings support a compliance-effectiveness paradox: high procedural activity can coexist with weak or inconsistent signals of substantive effectiveness. RAM assurance should therefore combine activity frequency with analytical quality, barrier health, control verification and action closure.

Keywords: Risk Assessment and Management; Shutdown and Turnaround Maintenance; Safety Performance; Spearman Correlation; Organisational Culture; Oil and Gas

INTRODUCTION

Shutdown and Turnaround Maintenance (STAM) projects represent high-density operational interventions in which production facilities are systematically halted for inspection, repair, and equipment upgrade activities. Their compressed timelines, concurrent execution of multiple high-hazard tasks, and complex multi-contractor work environments create conditions that substantially amplify safety risk [1, 2]. In Nigeria's oil and gas sector—where ageing upstream infrastructure necessitates frequent STAM cycles—the stakes of inadequate safety governance during STAM operations are particularly significant [3]. Nigeria's National Bureau of Statistics [3] reports that the petroleum sector contributed 5.7% to GDP in 2022; separately, the Department of Petroleum Resources has documented persistent injury and fatality rates in upstream operations, with STAM-phase activities consistently over-represented in incident statistics [4]—underscoring the urgent need for effective RAM governance frameworks in this context.

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The oil and gas industry globally combines elevated-pressure processes, volatile substances, and intricate socio-technical systems in ways that make structured risk management not a best practice but an operational necessity [5]. Failures during STAM activities have historically precipitated serious incidents, significant environmental harm, and substantial financial losses, often attributable less to the absence of formal safety procedures than to the degradation of those procedures under real operational conditions [6]. Persistent challenges in Nigeria specifically—including gaps in risk communication, inconsistent contractor safety alignment, and variable enforcement of safety protocols—have been well documented [7, 8].

The central tension motivating this study concerns the relationship between RAM tool deployment and safety outcomes. The literature identifies a widespread tendency to treat usage frequency as a proxy for safety effectiveness—a 'tick-the-box' orientation in which procedural execution substitutes for substantive risk engagement [9, 10]. This disposition is particularly concerning in developing-economy operational contexts, characterised by high production pressure, where compliance documentation may obscure accumulated systemic vulnerability [11].

Reason's foundational argument that safety performance is shaped as much by organisational culture as by formal systems [12] underpins the study's philosophical orientation. Rather than statistically testing the frequency–incident relationship in isolation, this study examines practitioners' perceptions and evaluations of RAM tools, the organisational conditions associated with implementation quality during STAM operations, and what organisational conditions determine whether those tools produce genuine risk reduction. In so doing, it addresses an important evidential gap in the Nigerian STAM literature.

Study contribution

The study contributes in three ways. Empirically, it provides respondent-level evidence from an under-researched Nigerian STAM setting. Methodologically, it separates tool frequency, distinct perception items and incident experience, and uses EFA and robust regression to test whether a composite effectiveness interpretation is defensible. Theoretically, it develops a compliance-effectiveness paradox in which activity frequency is an observable process input, while implementation quality, perceived effectiveness and verified outcomes remain distinct analytical levels.

Research Objectives

The study is guided by the overarching question: In what ways do RAM practices shape the safety experiences and perceptions of workers in STAM projects? The specific testable sub-questions are: (i) Do different RAM tools vary systematically in their perceived usage frequency? (ii) Are usage frequency and effectiveness perceptions associated across tool types? The specific objectives are:

- To examine the range of RAM tools deployed and the character of their practical application within STAM operations;
- To explore practitioners' perceptions of RAM tool effectiveness;
- To investigate how organisational and cultural factors shape implementation quality; and
- To develop evidence-based recommendations for strengthening RAM practice in future STAM operations.

LITERATURE REVIEW

For the purposes of this study, RAM tool effectiveness is defined as the extent to which a safety instrument produces genuine and measurable reduction in operational hazard exposure—as distinguished from mere procedural compliance. This distinction, following Hollnagel's [6] Safety-II framing, foregrounds the quality of safety work rather than its formal occurrence. This operational definition is cross-referenced with the measurement operationalisation in Section III.

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THEORETICAL FRAMEWORK

The study draws on three complementary frameworks. Reason's Swiss Cheese Model [13] situates safety incidents as products of the simultaneous alignment of latent failures across multiple organisational layers. No single RAM tool operates in isolation; systemic protection requires mutually reinforcing defensive layers. This model underscores why high deployment frequency of any one tool cannot, in itself, guarantee safety if systemic weaknesses persist elsewhere. Reason's later refinement of the model [12] further distinguishes between active failures and latent conditions—a distinction directly applicable to the implementation quality deficits identified in this study.

Leveson's Systems-Theoretic Accident Model and Processes (STAMP) [14] reconceptualises safety as a control problem. Ineffective RAM implementation is understood as a product of inadequate safety constraints and deteriorating inter-component control relationships within the socio-technical system—not individual error. STAMP directs analytical attention towards the organisational structures, communication channels, and feedback mechanisms through which safety governance is sustained or eroded.

Rasmussen's Dynamic Safety Model [15] contributes a temporal dimension, arguing that organisations under persistent operational pressure will drift towards safety boundaries unless active monitoring and corrective feedback loops are maintained. This framework is directly relevant to STAM environments, where schedule pressure and resource competition can progressively degrade the substantive quality of safety tool application even as formal compliance is sustained.

Applied conjointly, these three frameworks provide a theoretically coherent explanation for a specific empirical paradox: how an organisation can sustain high RAM tool deployment frequency while simultaneously experiencing persistent safety incidents. Reason's Swiss Cheese Model [13] performs diagnostic work—identifying where latent conditions accumulate across governance layers. STAMP [14] performs structural work—locating the source of ineffectiveness in deteriorating inter-component control relationships and communication failures. Rasmussen's Dynamic Safety Model [15] performs temporal work—explaining the drift mechanism by which organisations migrate towards risk boundaries under sustained operational pressure. Each framework addresses a different analytical dimension of the compliance–effectiveness paradox, and their conjoint application provides an explanatory architecture that no single framework could supply alone.

Risk assessment and management has long been recognised as foundational to occupational safety in process-intensive industries [16]. Evidence consistently indicates that effective RAM practice depends not merely on the selection and frequency of safety tools but on the organisational infrastructure—leadership, communication, training, and cultural orientation—through which those tools are enacted and embedded.

Clarke's integrative safety climate model [17] argues that safety outcomes are products of transparency, trust, and adaptive capacity within the safety system—not procedural compliance alone. Weick and Sutcliffe's high-reliability organisation (HRO) framework [18] extends this argument, establishing that the capacity to anticipate and manage hazards depends on collective organisational mindfulness: a quality that formal procedures can support but not substitute. In addition to these behavioural and organisational perspectives, a growing strand of literature addresses the role of technology-mediated control in enhancing RAM governance—directly relevant to STAMP's conceptualisation of deteriorating inter-component control relationships. An emerging body of literature on digital and AI-assisted risk management tools—including real-time risk dashboards, AI-assisted Hazard and Operability (HAZOP) analysis, and digital permit-to-work systems [19, 20]—indicates that technology-enabled tools may substantially improve the quality of dynamic risk monitoring in STAM environments. This literature is directly relevant to this study's recommendation for enhanced Risk Register accessibility and real-time update capability.

Implementation quality, safety climate and leading indicators

The compliance–effectiveness distinction is reinforced by research on safety climate, safety culture and leading indicators. Safety climate reflects shared perceptions of the priority accorded to safety and predicts participation

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and compliance behaviours [21, 22, 23]. Reviews caution that culture and climate should not be reduced to documentation counts because their effects depend on leadership, learning and enacted practice [24, 25, 26]. In process industries, leading indicators are most useful when they monitor barrier health, corrective-action quality and weak signals rather than the number of completed forms [27, 28, 29]. Resilience engineering likewise emphasises adaptive capacity, learning and the ability to respond before loss occurs [30, 31]. These perspectives support treating RAM frequency as an exposure or activity measure, while implementation quality and organisational conditions remain the more plausible mechanisms linking tools to outcomes.

METHODOLOGY

Research Design and Philosophical Stance

This study used a theoretically informed cross-sectional quantitative survey design. The unit of analysis was the individual respondent, and the empirical analysis remained quantitative throughout. Reason's layered-defence model, Leveson's STAMP framework and Rasmussen's dynamic safety model were used subsequently as interpretive lenses; they were not operationalised as measured constructs and no independent qualitative dataset or thematic analysis was undertaken. This distinction preserves the explanatory value of systems-safety theory without presenting theoretical interpretation as a separate empirical method.

Study Context and Participants

The study was conducted within a major Nigerian upstream petroleum operation that underwent significant organisational transition following corporate divestment. The participant group comprised 148 professionals selected through criterion-based purposive sampling, in which selection required that respondents met specific operational inclusion criteria—ensuring contextual depth rather than mere accessibility.

The selection criteria required respondents to have participated in at least one complete STAM project during 2020-2024 and to occupy a role involving execution, support or oversight of STAM activities. Of 178 eligible professionals approached, 148 returned complete questionnaires, giving an 83.1% response rate. Because individual-level information for non-respondents was unavailable, a formal non-response-bias test was not conducted.

Participants were drawn from Operations (n = 52), Maintenance (n = 31), HSE (n = 22), Shutdown/Startup (n = 16), Engineering (n = 14), Planning and Project Controls (n = 12), and Training and Development (n = 1), totalling 148 participants. The marginal representation of Training and Development (n = 1) is noted as a material analytical limitation, discussed further in Section VII: this function plays a central role in RAM training quality, and its underrepresentation may restrict the breadth of perspective captured on training adequacy and may limit the generalisability of training-related findings. This departmental spread nonetheless captures both core operational and supporting functional perspectives on RAM practice.

Sixty-one respondents (41.2%) reported 10-15 years of STAM experience and 49 (33.1%) reported at least 15 years. The sample therefore contains substantial operational experience, although long experience also implies unequal cumulative opportunity for incident exposure and does not independently validate retrospective judgements.

Data Collection and Analysis

Data were gathered through a structured questionnaire administered electronically via Google Forms to all participants. Section A captured demographic and professional profiles; Section B elicited frequency ratings for four RAM tools—HAZOP, JSA, Toolbox Talks, and Risk Registers—on a 5-point Likert scale (1 = Never; 5 = Always); Section C gathered five perceived effectiveness assessments on the same 5-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree), covering: RAM tool effectiveness in preventing incidents (C1), proper field implementation (C2), safety communication improvement (C3), training adequacy (C4), and management commitment to RAM (C5); and Section D collected safety incident experience data. For the purposes of Section D, a 'safety incident' was defined, within the questionnaire instrument itself, as any unplanned work event

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resulting in injury, illness, dangerous occurrence, or near-miss that was—or should have been—reportable under the organisation's incident management protocol. This definition is consistent with the UK Health and Safety Executive's RIDDOR framework and the Nigerian Department of Petroleum Resources' Offshore Safety Guidelines.

Content validity was established through academic supervisor review and industry practitioner consultation (three HSE professionals with a minimum of ten years' STAM experience), followed by pilot testing with five participants for instrument clarity and appropriateness, after which minor wording revisions were made to two items. The overall RAM effectiveness assessment reported in the correlation analysis represents a composite mean score derived from the five C-section items (C1–C5), which together form the study's perceived RAM effectiveness scale.

The internal consistency of the two Likert-scale sections was assessed using Cronbach's alpha. The usage frequency scale (B1–B4) yielded $\alpha = 0.683$, indicating acceptable internal consistency. The perceived effectiveness scale (C1–C5) yielded $\alpha = 0.528$, indicating marginal reliability.

The lower alpha for the C scale reflects genuine heterogeneity across its five items, each measuring a distinct dimension of effectiveness perception rather than a unidimensional construct. These alphas are reported in the interest of full transparency and do not disqualify the scales from analytical use, but do caution against treating the C composite as a fully unidimensional effectiveness index. To address this limitation, both composite-level and item-level Spearman correlations are reported in Section IV.

The analytical process combined descriptive and inferential procedures. Means, medians and standard deviations summarised the item distributions, while Spearman correlations assessed ordinal associations. The dimensionality of C1-C5 was explored using a two-factor exploratory factor analysis with varimax rotation after Kaiser-Meyer-Olkin and Bartlett diagnostics.

Because C1-C5 displayed marginal internal consistency, the composite mean was retained only as a sensitivity outcome in a multiple linear regression with heteroscedasticity-consistent (HC3) standard errors. Predictors were HAZOP, JSA, toolbox-talk and risk-register frequency, experience category, direct RAM involvement and number of shutdown years.

Respondents reporting an incident were compared with those reporting none using two-sided Mann-Whitney U tests; uncertain responses were excluded from these comparisons. Effect sizes were expressed as rank-biserial correlations. All analyses used the 148 complete respondent records.

RESULTS

The primary statistical pattern was a marked difference in reported tool frequency combined with weak associations between frequency and perceived effectiveness. Composite correlations were weak and non-significant, but the composite is treated only as a sensitivity outcome because C1-C5 showed low internal consistency. Principal interpretation therefore emphasises item-level results, EFA diagnostics, the robust regression sensitivity analysis and incident-group comparisons.

Tool-frequency profile and task-level concentration

RAM tool usage data reveal a pronounced institutional hierarchy. JSA recorded the highest mean usage score ($M = 4.53$, $SD = 0.55$, $Mdn = 5.0$), followed closely by Toolbox Talks ($M = 4.35$, $SD = 0.75$, $Mdn = 5.0$), while HAZOP studies ($M = 2.30$, $SD = 1.31$, $Mdn = 2.0$) and Risk Registers ($M = 2.27$, $SD = 1.37$, $Mdn = 2.0$) were substantially less deployed. This two-fold disparity between task-level and system-level tool usage is a structurally meaningful finding. Figure 1 presents mean frequency scores across all four tools.

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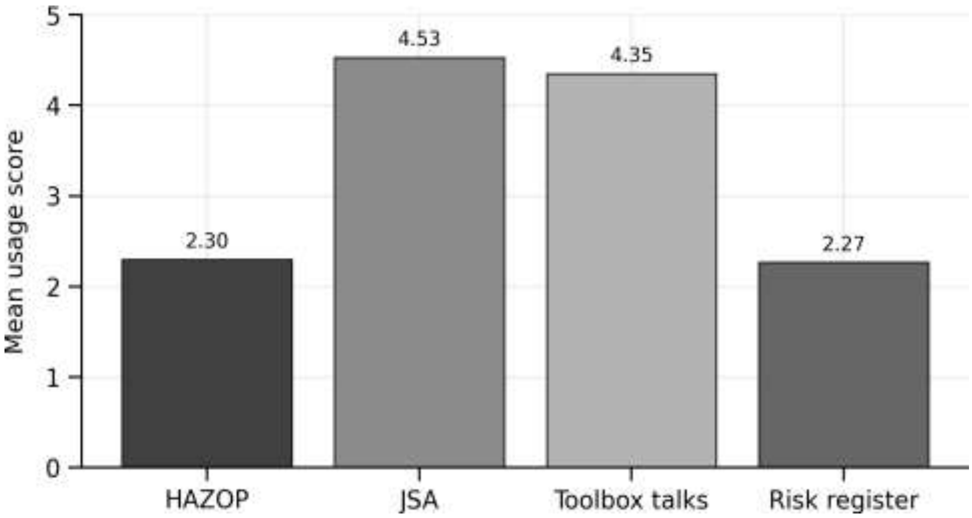

Figure 1. Mean frequency of RAM tool usage across participants.

The high reported frequency of JSA and toolbox talks indicates that these task-level activities are embedded in routine execution. Frequency alone, however, does not show whether the activities were hazard-specific, participatory or responsive to changing conditions. The lower frequency of HAZOP is also partly consistent with its concentration in planning and major-change reviews rather than daily execution. The more consequential result is the low reported updating of risk registers during execution, because dynamic review is intended to maintain visibility of emerging and unresolved risks.

The progressive increase in respondent participation peaking in 2024 ($n = 83$) may reflect growing organisational documentation of risk management activity; however, an alternative explanation deserves acknowledgement: 2024 was the most recent year and thus the most readily recalled by respondents—a recency effect that should be considered when interpreting the temporal trend.

System-level tool patterns and perceived prevention

Despite its low deployment frequency, the Risk Register demonstrated notable patterns in its inter-item correlations and effectiveness associations. Descriptive statistics and the Spearman correlation matrix ($n = 148$, two-tailed) are presented in Tables 1 and 2 respectively. The correlation matrix reveals that HAZOP and Risk Register usage are strongly co-occurring (B1–B4: $\rho = 0.609$, $p < .001$), indicating that organisations deploying one system-level tool tend to deploy the other—a pattern consistent with an integrated safety governance culture. The association between Risk Register usage and perceived tool effectiveness in preventing incidents (B4–C1: $\rho = 0.194$, $p = .018$) was the strongest B–C correlation observed and was statistically significant, albeit modest.

Table 1: Descriptive Statistics for Tool Usage Frequency (B1–B4) and Perceived Effectiveness Items (C1–C5)

Primary survey data, n = 14

Variable	Mean (M)	SD	Median	Scale Range
B1 – HAZOP Frequency	2.3	1.31	2	1–5
B2 – JSA Frequency	4.53	0.55	5	1–5
B3 – Toolbox Talk Frequency	4.35	0.75	5	1–5
B4 – Risk Register Frequency	2.27	1.37	2	1–5
C1 – RAM Prevents Incidents	4.31	0.68	4	1–5
C2 – Proper Field Implementation	4.07	0.87	4	1–5

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C3 – Safety Communication	4.07	0.87	4	1–5
C4 – Training Adequacy	4.03	0.88	4	1–5
C5 – Management Commitment	3.97	0.93	4	1–5

Table 2: Spearman Rank-Order Correlation Matrix — Tool Usage Frequency (B1–B4) and Perceived Effectiveness Items (C1–C5)

Primary survey data, n = 148. * p < .05; ** p < .01; *** p < .001 (two-tailed)

	B1	B2	B3	B4	C1	C2	C3	C4	C5
B1 (HAZOP)	1.000	0.310***	0.272***	0.609***	0.258**	0.065	0.156	−0.119	0.019
B2 (JSA)	0.310***	1.000	0.090	0.169*	0.142	0.109	0.194*	−0.047	0.032
B3 (TBT)	0.272***	0.090	1.000	0.248**	0.158	0.036	0.113	0.047	0.003
B4 (Risk Reg.)	0.609***	0.169*	0.248**	1.000	0.194*	0.029	0.087	−0.062	0.028
C1	0.258**	0.142	0.158	0.194*	1.000	0.071	0.081	−0.045	0.230**
C2	0.065	0.109	0.036	0.029	0.071	1.000	0.119	0.373***	0.245**
C3	0.156	0.194*	0.113	0.087	0.081	0.119	1.000	0.187*	0.163*
C4	−0.119	−0.047	0.047	−0.062	−0.045	0.373***	0.187*	1.000	0.205*
C5	0.019	0.032	0.003	0.028	0.230**	0.245**	0.163*	0.205*	1.000

Examination of item-level correlations in Table 2 reveals several substantively important patterns beyond the composite-level findings. Notably, HAZOP usage frequency (B1) demonstrates the strongest individual association with perceived RAM effectiveness in preventing incidents (B1–C1: $\rho = 0.258$, $p < .01$), suggesting that system-level hazard identification tools are more closely linked to incident-prevention confidence than task-level tools. Equally significant is the strong positive correlation between perceived proper field implementation and training adequacy (C2–C4: $\rho = 0.373$, $p < .001$), indicating that practitioners who perceive poor field implementation also perceive inadequate training—a pattern directly relevant to the competency-based recommendations advanced in Section V. These item-level insights complement the composite analysis and are presented transparently given the acknowledged heterogeneity of the C-scale.

Practitioners' higher confidence in the Risk Register reflects a recognition—whether or not consciously articulated—of the functional distinction between tools that address discrete task-level hazards and those that serve as system-wide risk governance instruments. According to Sutcliffe [32], 'sensitivity to operations'—defined as the capacity for continuous, accurate situational awareness across the system—is a hallmark of high-reliability performance, and it is precisely this quality that a well-maintained Risk Register can operationalise.

The lower reported use of risk-register updating identifies a governance question rather than proving a control failure. Plausible explanations include phase-specific use, restricted access, unclear ownership or insufficient integration with daily coordination, but these mechanisms were not measured. Future audits should examine register currency, action ownership, change traceability and whether current risk information reaches task-level briefings.

Incident experience and group comparisons

Building on the absence of significant frequency–effectiveness correlations established above, a majority of respondents (62.8%) reported having experienced at least one safety incident during a STAM project, against 34.5% who reported none and 2.7% who were uncertain. The 'uncertain' response category warrants interpretive attention: this group may comprise individuals who experienced safety events not formally classified as

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incidents, or who were uncertain about the definitional threshold applied. Their responses have been retained in the dataset as a distinct category and excluded from incident frequency calculations to avoid interpretive distortion. Figure 2 presents the distribution of reported safety incident experiences.

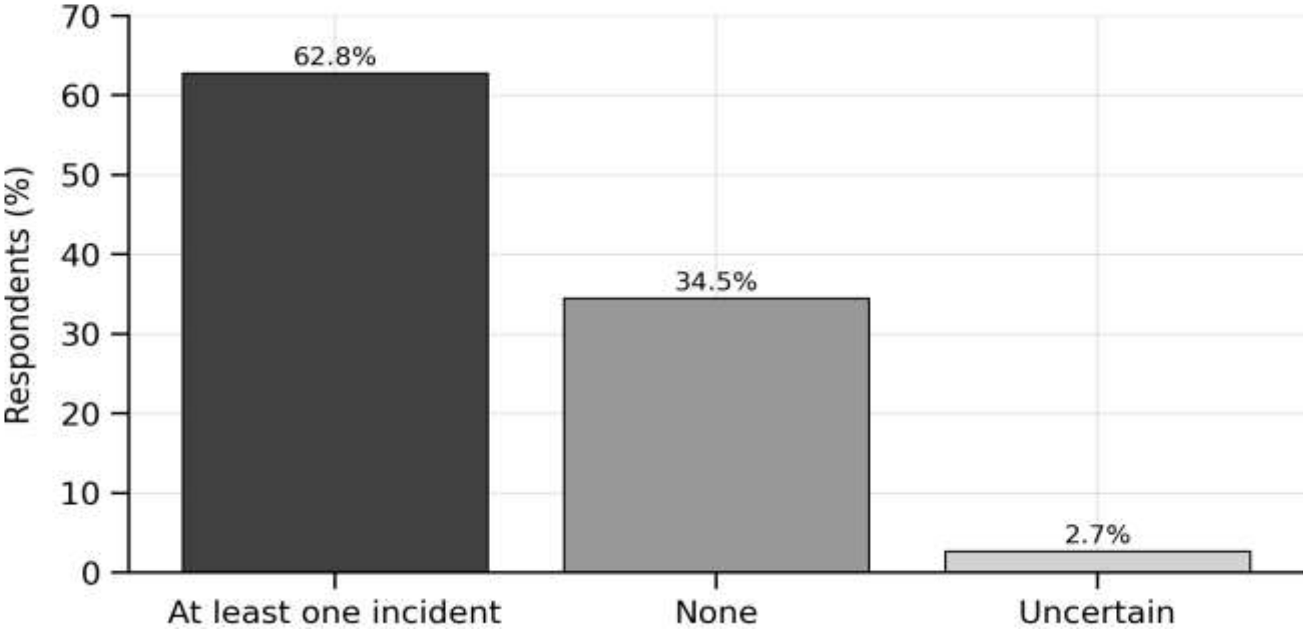

Figure 2. Distribution of reported safety incident experiences.

The coexistence of frequent JSA and toolbox-talk activity with common cumulative incident experience motivates the compliance-effectiveness paradox, but it does not demonstrate that the tools failed. Incident experience may pre-date current practices, reflect longer or higher-hazard exposure, or prompt stronger subsequent use. The incident-group comparisons therefore support a reactive-learning interpretation only as a proposition for longitudinal testing, not as a causal conclusion.

Measurement structure and organisational perceptions

Connecting to Objective 3—the investigation of organisational and cultural factors shaping implementation quality—the fourth theme concerns the decisive influence of human and organisational factors on whether formally deployed RAM tools produce genuine safety improvement. The systematic divergence between usage frequency and effectiveness ratings—most clearly illustrated by the non-significant Spearman correlations between all four tool usage frequencies and overall effectiveness perception—indicates a practitioner-level awareness that procedural frequency and functional effectiveness are not equivalent.

Agwu [33] documented that prevailing organisational culture in Nigeria's oil and gas sector—particularly norms that privilege production continuity over safety investment—can systematically undermine the quality of RAM practice. Aluko and Arewa [34] similarly identified the gap between formal procedure and enacted field behaviour as most pronounced where leadership modelling of safe practice is inconsistent or absent. Ehiaguina and Moda [11] characterised this as a fundamental disconnection between safety policy and operational reality, a finding directly corroborated by the present study's data.

Communication practices emerge as a further critical organisational variable. Zara et al. [39] established that Nigerian petroleum organisations characterised by transparent leadership communication and psychologically safe hazard reporting demonstrated superior capacity to translate risk assessments into effective operational actions. Niknezhad et al. [35] identified communication failure as among the most frequently implicated factors in industrial incidents, particularly where hierarchical norms suppress the upward escalation of safety concerns. These findings resonate directly with the present study's data: the persistence of safety incidents in an environment of formally robust RAM deployment is consistent with a communication and leadership infrastructure that does not fully support the substantive quality of risk engagement.

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Inferential analyses

Exploratory factor analysis produced a KMO value of .610 and a significant Bartlett test, chi-square(10) = 54.70, $p < .001$, indicating marginal but usable shared variance. The first two eigenvalues were 1.75 and 1.09 and together accounted for 56.8% of total variance. After varimax rotation, training adequacy loaded most strongly on Factor 1 (.677), accompanied by field implementation (.446), whereas incident prevention (.587) and management commitment (.525) loaded primarily on Factor 2. Safety communication had a low communality (.093). This pattern does not support a strong single effectiveness construct; it instead suggests two tentative domains: implementation capability and prevention-leadership perception. Given that each domain contains few indicators, the factors are interpreted cautiously and are not promoted as validated scales.

Table 3. Exploratory factor analysis of C1-C5

Item	Factor 1	Factor 2	Communality
C1 Incident prevention	.039	.587	.346
C2 Field implementation	.446	.294	.286
C3 Safety communication	.286	.105	.093
C4 Training adequacy	.677	.035	.459
C5 Management commitment	.283	.525	.356

The robust multiple-regression model was not significant, R2 = .031, adjusted R2 = -.018, F = 0.62, p = .741. None of the four tool-frequency predictors, experience, direct RAM involvement or shutdown-year count independently predicted the composite effectiveness score. Coefficients were small, and every 95% confidence interval crossed zero. These results reinforce the interpretation that frequency alone is a weak explanatory measure. They should not be taken as evidence that RAM tools lack operational value, because the outcome is perceptual and the composite has limited reliability.

Table 4. Robust multiple regression predicting composite perceived effectiveness

Predictor	B	Robust SE	p
HAZOP	0.014	0.048	0.771
JSA	0.065	0.084	0.438
Toolbox talks	0.018	0.064	0.772
Risk register	0.037	0.047	0.438
Experience	0.031	0.050	0.538
Direct RAM involvement	0.043	0.138	0.755
Shutdown-year count	-0.007	0.055	0.905

Incident-group comparisons showed a selective rather than general pattern. Respondents reporting incident experience had higher mean JSA frequency (4.60 versus 4.39; U = 2795.5, p = .042, rank-biserial r = .179), incident-prevention perception (4.39 versus 4.16; U = 2824.0, p = .032, r = .191) and field-implementation perception (4.20 versus 3.84; U = 2824.5, p = .044, r = .191). The composite effectiveness scores did not differ significantly (4.15 versus 4.01; U = 2709.0, p = .155, r = .142). These small differences may reflect greater exposure, post-incident procedural reinforcement or heightened risk awareness. They do not demonstrate that greater tool use caused incidents or that incidents improved effectiveness perceptions.

Table 5. Selected incident-group comparisons

Outcome	Incident mean	No-incident mean	U	p	r
JSA frequency	4.60	4.39	2795.5	.042	.179
Incident prevention	4.39	4.16	2824.0	.032	.191
Field implementation	4.20	3.84	2824.5	.044	.191
Composite effectiveness	4.15	4.01	2709.0	.155	.142

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DISCUSSION

Taken together, the findings identify a bounded compliance-effectiveness paradox: visible RAM activity was high for selected task-level tools, yet frequency explained little variation in broader perceptions of implementation and effectiveness. The paradox concerns measurement and governance rather than opposition between compliance and safety. It is interpreted through systems-safety theory while remaining constrained by the single-site, cross-sectional and self-report design.

Within Reason's Swiss Cheese Model [12, 13], the findings are readily intelligible. High-frequency deployment of task-level tools addresses gaps in one or two defensive layers but does not close the systemic vulnerabilities created by leadership deficiencies, communication breakdowns, and cultural complacency. The safety system's overall protective capacity reflects the strength of its weakest layer, not its most frequently exercised one. STAMP [14] directs attention to the same dynamic from a control-theoretic perspective: the persistent safety incidents are consistent with inadequate safety constraints at the management and organisational levels, even where field-level tool compliance appears robust.

The strong respondent-level co-occurrence of HAZOP and risk-register use (rho = .609, $p < .001$) suggests that participants who encountered one system-level tool also tended to encounter the other within this organisation. It does not justify an organisation-level generalisation. The robust regression explained only 3.1% of variance in the composite sensitivity outcome and no predictor was independently significant, reinforcing the conclusion that frequency is an incomplete explanatory measure.

The chronic underdeployment of Risk Registers in favour of task-level tools represents a systematic misallocation of governance effort—one that prioritises visible compliance activity over the system-level risk intelligence that complex STAM environments most require. AlNoaimi and Mazzuchi [36] argued that robust risk frameworks succeed when they enable centralised information sharing and dynamic adaptation; the present study's data are consistent with this view, though the modest magnitude of the B4–C1 correlation ($\rho = 0.194$, $p = .018$) cautions against overstating the relationship within this study's bounded context.

Rasmussen's Dynamic Safety Model [15] explains the mechanism of this misallocation: under sustained operational pressure, organisations drift towards the boundaries of safe behaviour unless active feedback and monitoring mechanisms continuously pull them back. A live, well-maintained Risk Register constitutes precisely such a feedback mechanism; its neglect allows risk-state drift to accumulate undetected behind the facade of routine tool compliance.

It is important to acknowledge that not all evidence in the RAM effectiveness literature supports the central finding that compliance frequency is decoupled from safety outcomes. Several quantitative studies in comparable industrial settings have identified positive statistical relationships between tool usage frequency and incident rate reductions—particularly in contexts characterised by strong regulatory oversight and high management commitment to safety [16]. The divergence between those findings and the present study's results is best understood through the lens of contextual difference: Nigeria's petroleum sector presents a distinctive combination of production pressure, post-divestment organisational instability, and variable enforcement capacity that may amplify the gap between procedural compliance and substantive risk governance. This contextual specificity does not undermine the study's contribution but clarifies its scope and conditions of applicability within this post-divestment upstream context and potentially analogous settings.

The predominantly single-incident profile (Mdn = 1.0 per respondent) offers a partial counterpoint. In Weick and Sutcliffe's terms [18], a safety system that contains initial failures and prevents their escalation demonstrates meaningful resilience, even where preventive capacity remains limited. This reactive resilience—evidenced by the relatively low recurrence rate beyond initial incident exposure—is a genuine organisational achievement. The developmental challenge is to extend this reactive capacity into pre-incident anticipation.

The findings can be compared cautiously with high-reliability organising principles, but they do not support classifying the organisation's maturity. Frequent frontline routines coexist with less frequent system-level updating, while the survey did not directly measure deference to expertise, mindfulness, barrier health or anticipatory capability. The HRO comparison is therefore used as a diagnostic agenda for future measurement rather than an organisational rating.

Table 6. Evidence-Based HRO Gap Analysis For The Study Organisation

HRO principle	Study evidence	Interpretation
Preoccupation with failure	62.8% reported at least one incident; low recurrence beyond the first event	Partial: learning appears stronger after events than before them
Reluctance to simplify	Task-level tools dominate while system-level tools are less used	Weak to partial: risk may be simplified into routine compliance
Sensitivity to operations	JSA and toolbox talks are frequent; live Risk Register use is limited	Partial: frontline visibility is stronger than system-wide visibility
Commitment to resilience	Median incident count was 1.0 among incident-reporting respondents	Moderate: evidence of containment and corrective learning
Deference to expertise	Survey did not directly measure decision authority or escalation to experts	Not established: requires direct measurement in future research

Taken together, these findings affirm the conclusions of Ehiaguina and Moda [11] that RAM effectiveness is a complex interplay of structured processes, organisational culture, leadership quality, and workforce engagement. They contribute to an accumulating body of evidence—including Niknezhad et al. [35] and Zara et al. [39]—that challenges compliance-based approaches to safety management.

Implications for Practice

Based on the study's findings, four evidence-grounded practical recommendations are advanced, differentiated by stakeholder group.Table 7. Translation of findings into governance actions

Finding	Governance gap	Recommended action	Primary owner
High JSA and toolbox-talk frequency	Potential ritualisation and weak analytic depth	Audit content quality, hazard specificity and corrective-action follow-through	HSE and operations leaders
Low Risk Register use	Limited dynamic, system-level risk visibility	Assign ownership; review daily; enable field-accessible updates	Operations and planning managers
Training linked to field implementation	Competence may constrain implementation quality	Use scenario-based assessment and refresher coaching	Training providers and HSE
Frequency does not predict composite effectiveness	Activity counts are weak performance proxies	Adopt leading indicators for barrier health and action closure quality	Senior management and regulators

For Operations Managers: Risk Registers should be reintegrated into daily STAM workflows as dynamic governance instruments, with defined ownership, real-time update protocols, and digital infrastructure enabling field accessibility. Their demonstrated contextual association with perceived RAM effectiveness identifies them as high-leverage safety governance investments [36]. Specific actions should include: embedding Risk Register review into daily STAM toolbox meetings; assigning named accountable individuals for update compliance; and procuring mobile-accessible digital risk register platforms.

ISSN 2278-2540 | DOI: 10.51583/IJLTEMAS | Volume XV, Issue VIII, August 2026

For HSE Leaders: RAM performance monitoring frameworks should be anchored in quality indicators—near-miss reporting rates, Risk Register update frequency, JSA specificity scores, and timeliness of corrective action closure—rather than simple tool-use frequency. These metrics provide a credible foundation for discriminating between tools that are performed and tools that are effective [37]. KPI frameworks and audit criteria should be reoriented from procedural frequency counts to substantive implementation quality indicators.

For Regulators (NUPRC): Regulatory inspection criteria should be redesigned to assess the quality and analytical depth of RAM tool application, rather than documentation frequency alone. Penalty frameworks that treat procedural compliance as equivalent to safety effectiveness create perverse incentives that the present data confirm are operationally counterproductive.

For Training Providers: RAM training must shift from procedural familiarisation to scenario-based, reflective learning that equips practitioners to interrogate hazards critically rather than execute safety tools as administrative requirements. Evidence from systematic reviews of occupational health and safety management system interventions confirms that training programmes anchored in active learning and reinforcement are significantly more effective in sustaining behavioural change than one-time procedural instruction [38]. Competency-based training frameworks should replace procedural checklists as the primary training design paradigm.

Communication structures within STAM operations must be redesigned to support genuinely open hazard reporting at all organisational levels. The evidence consistently links communication failures and hierarchical reporting norms to incident prevalence [35, 39]; creating psychologically safe escalation channels is a prerequisite for translating formal RAM compliance into substantive safety improvement.

CONCLUSION

The most important finding of this study is the empirically confirmed divergence between RAM tool deployment frequency and genuine safety effectiveness in a post-divestment Nigerian upstream STAM context. Spearman rank-order correlations between tool usage frequency and overall perceived RAM effectiveness were weak and non-significant for all four tools (all $\rho < 0.16$, all $p > .05$), challenging the assumption that procedural compliance frequency constitutes a reliable safety proxy. The Risk Register—systematically underutilised relative to task-level tools—demonstrated the strongest pattern of co-occurrence with HAZOP usage ($\rho = 0.609$, $p < .001$) and the highest individual association with perceived effectiveness in preventing incidents ($\rho = 0.194$, $p = .018$) within this study's bounded single-organisation context.

Theoretically, these findings affirm the complementary explanatory power of Reason's Swiss Cheese Model, Leveson's STAMP, and Rasmussen's Dynamic Safety Model as integrated analytical tools for understanding how formally compliant organisations sustain persistent safety vulnerabilities. They also advance the HRO literature by empirically characterising a Nigerian STAM operator as exhibiting reactive rather than anticipatory resilience—a distinction with direct implications for the theory and measurement of safety maturity in developing-economy industrial contexts.

For practice, the study calls for a fundamental reorientation of RAM governance: from compliance-driven procedural execution towards quality-focused, leadership-supported, and culturally embedded risk management. This study contributes rigorous quantitative empirical evidence to the Nigerian STAM safety literature, offering context-specific insights directly relevant to safety managers, operational leaders, and regulatory authorities responsible for STAM safety performance in this post-divestment upstream context and comparable high-risk environments.

Limitations and Future Research

Several limitations warrant acknowledgement. The study concerns one organisation, uses a cross-sectional design, and relies on self-report, limiting causal and sector-wide inference. C1-C5 have low internal consistency ($\alpha = .528$), substantial construct undercoverage, and do not form a validated effectiveness scale. Common-method variance, social-desirability bias, recall bias, restricted rating ranges, unmeasured confounding, and

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multiple-testing risk may influence the associations. Incident experience was cumulative and lacked adequate timing, severity, type, and exposure adjustment. Departmental representation was uneven, including one Training and Development respondent. The survey did not directly measure safety climate, organisational culture, HRO principles, barrier health, or implementation quality through observation. Consequently, no conclusions about causality, verified effectiveness, organisational maturity, or the wider Nigerian sector are warranted.

Future research directions include:

1. Longitudinal designs covering at least three consecutive STAM cycles to test temporal stability and learning effects;

2. Multi-site studies across at least three operators to separate organisational effects from sector-wide patterns;

3. Mixed-method studies combining surveys, field observations, interviews and document-quality audits;

4. Multilevel modelling or structural equation modelling to test leadership, training and safety climate as mediators;

5. Prospective evaluations of digital risk registers, permit-to-work integration and AI-supported HAZOP systems.

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