IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

Integrated Advanced Risk Prioritization of Major Hazards in Oil and Gas Construction Projects

A Case-Based Study FMEA–AHP and Bow-Tie Analysis

Hemis Patel[1] and Dr. Neeta Banger[2]
Research Scholar[1], Professor[2]
Department of Industrial Safety Engineering[12]
Shiv Kumar Singh Institute of Technology & Science, Indore Madhya Pradesh, India

Abstract: *Oil and gas construction projects present a compound risk environment in which conventional construction hazards interact with hydrocarbon-process interfaces, temporary works, lifting, excavation, electrical activities, hot work and simultaneous operations (SIMOPS). This paper develops and demonstrates an integrated risk-prioritization framework that retains the practicality of a conventional probability–severity risk matrix while adding failure-mode analysis, explicit multi-criteria weighting and barrier-based Bow-Tie analysis. A case-based analytical study was undertaken using hazard and control information contained in supplied Oil and Gas infrastructure Limited HIRA and process-safety documents, together with publicly disclosed company safety information. Twenty major hazard scenarios were structured into a comparative dataset. Traditional risk was calculated as probability multiplied by severity. Failure Mode and Effects Analysis (FMEA) was then applied using severity, occurrence, frequency and detectability, followed by an Analytic Hierarchy Process (AHP) weighting scheme of 0.40, 0.25, 0.20 and 0.15 respectively. The resulting normalized integrated index, termed the Fuzzy/FMEA-AHP-inspired Risk Priority Index (FRPI), was used to rank hazards and guide Bow-Tie barrier selection. The analytical results placed excavation collapse, suspended-load struck-by, SIMOPS/communication failure, work at height/man basket and buried-utility strike among the highest priorities. Illustrative control scenarios reduced the baseline P×S scores by approximately 33–67%, depending on the hazard. The study demonstrates that an integrated approach can discriminate between hazards that receive similar traditional risk scores and can translate risk ranking into auditable preventive and mitigative barriers. The numerical expert-rating dataset is explicitly treated as an analytical demonstration dataset where authenticated field ratings were not present; therefore, the paper does not claim that these illustrative values are measured site observations. The framework is intended for validation through an authenticated project HSE expert panel before operational adoption.*

Keywords: oil and gas construction; industrial safety; HIRA; FMEA; AHP; Bow-Tie analysis; risk prioritization; SIMOPS; process safety; Oil and Gas Infrastructure.

I. INTRODUCTION

Process safety and occupational safety are inseparable in oil and gas construction because construction work can be performed adjacent to operating or future hydrocarbon systems. The supplied process-safety reference emphasizes that oil and gas operations demand systematic control of hazards to protect personnel, assets and the environment. It also identifies multidisciplinary inputs from process, piping, mechanical, electrical and instrumentation engineering as important to the process safety design basis.

Construction projects additionally involve excavation, lifting, temporary structures, work at height, electrical connections, welding, material handling, mobile equipment and changing work-front conditions. When these activities

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

occur near hydrocarbon facilities, the consequences of loss of containment, ignition or interface failure can be substantially greater than those associated with an isolated construction task.

Conventional HIRA is a practical first-line tool because it is understandable at the work-front and can rapidly classify hazards. The supplied Oil and Gas HIRA uses a five-point severity scale and five-point probability scale and calculates risk as Risk = Severity × Probability. However, a matrix can produce tied scores and may not distinguish hazards with different exposure frequencies, failure-mode occurrence characteristics or detectability.

The present study therefore explores an integrated framework in which traditional HIRA is retained as the screening layer, FMEA adds failure-mode attributes, AHP makes the decision weights explicit, and Bow-Tie analysis converts priority scores into barrier requirements. The objective is not to replace established process-safety studies such as HAZOP, LOPA, QRA or EERA, but to provide a structured bridge between work-front risk assessment and management-level prioritization.

1.1 Research Problem and Motivation

The central research problem is the prioritization of major hazards in oil and gas construction when many scenarios are rated at or near the same traditional risk level. A project may have several high-risk tasks simultaneously, yet HSE resources for inspections, engineering review, permit verification and management attention are finite. A decision-support layer is therefore required to identify which hazards deserve the earliest and most intensive barrier verification.

The supplied company material indicates that Oil and Gas maintains an ISO 45001:2018-aligned occupational health and safety management system, uses site-specific HSE plans, formal hazard identification and risk assessment, Safe Work Method Statements, Permit-to-Work systems, worker hazard reporting and Behaviour-Based Safety initiatives. The company's disclosure also identifies working at height, excavation, material handling and lifting as high-risk activities requiring strengthened controls.

1.2 Research Objectives

- To establish a source-derived hazard universe for major oil and gas construction interfaces.
- To formulate a conventional probability–severity HIRA baseline for comparative analysis.
- To rank hazards using FMEA attributes representing severity, occurrence, frequency and detectability.
- To apply AHP to make the relative importance of decision criteria explicit and auditable.
- To integrate the weighted criteria into a normalized risk-priority index and compare the ranking with traditional HIRA.
- To translate the highest priorities into preventive and mitigative barriers using Bow-Tie logic.
- To demonstrate residual-risk reduction and identify implementation requirements for project HSE management.

1.3 Research Questions and Hypothesis

- Which hazard scenarios dominate the risk profile of oil and gas construction interfaces?
- Does the conventional P×S matrix provide adequate differentiation among major hazards?
- Can FMEA and AHP provide a more discriminating prioritization?
- How can numerical priorities be translated into barrier-management actions?
- Which control strategies provide the greatest reduction in residual probability?

H1: An integrated FMEA–AHP–Bow-Tie framework provides more discriminating and decision-oriented prioritization than a traditional probability × severity matrix. H0: The integrated framework does not provide a meaningful improvement in prioritization beyond the conventional matrix.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

II. LITERATURE REVIEW AND RESEARCH GAP

2.1 Conventional HIRA and Risk Matrices

Risk matrices remain widely used because they provide a simple visual representation of likelihood and consequence. In construction, the method is particularly useful for work permits, job safety analysis and daily planning. Its main limitation is coarse categorization: scenarios with different underlying mechanisms can receive the same numerical product. The supplied Oil and Gas infrastructure HIRA illustrates this issue through a five-by-five matrix and a defined relationship between severity, probability and risk.

2.2 FMEA and Risk Priority Number

FMEA structures risk around potential failure modes, their effects, causes and controls. Classical RPN is commonly represented as the product of severity, occurrence and detectability. IEC 60812 provides a formal framework for FMEA/FMECA. The method is useful for prioritization but can be sensitive to ordinal scales and may generate identical RPN values from different combinations of criteria.

2.3 Fuzzy and Multi-Criteria Extensions

Fuzzy FMEA research addresses uncertainty in linguistic ratings and the limitations of crisp ordinal scales. Multi-criteria decision-analysis approaches such as AHP, TOPSIS and related methods make criterion importance explicit and can reduce ranking ambiguity. The present work adopts a pragmatic AHP-weighted normalization rather than claiming a full fuzzy-inference engine; the term 'fuzzy/FMEA-AHP-inspired' is used in the manuscript to distinguish the framework from a validated fuzzy expert system.

2.4 Bow-Tie Analysis and Barrier Management

Bow-Tie analysis links threats to a top event and then to consequences, with preventive barriers on the left side and mitigative barriers on the right. Its principal value in this study is managerial: once a hazard is prioritized numerically, the organization can define what barrier must exist, what evidence demonstrates its presence and how frequently it should be verified.

2.5 Process-Safety Studies in Oil and Gas

The supplied process-safety reference describes HAZOP, SIL, LOPA, HAZAN, QRA, EERA, Fire and Gas Mapping, HSE dossiers, SIMOPS and PHSER. These methods operate at different levels of the project lifecycle. The proposed framework is positioned as a complementary risk-prioritization layer for construction interfaces rather than as a replacement for these specialized studies.

2.6 Recent Research Direction

Recent research trends include dynamic risk analysis, machine-learning-supported prioritization, risk–cost optimization and integration with BIM or digital-twin environments. These directions suggest that a static risk register can evolve into a continuously updated decision-support system once sufficiently large and authenticated field datasets are available.

2.7 Research Gap

Gap	Existing limitation	Need	Present study response	Status
G1	Traditional P×S matrix	Useful screening but frequent tied scores	Add occurrence, frequency and detectability	Addressed
G2	Classical FMEA/RPN	Ranking may depend strongly on ordinal multiplication	Use explicit AHP criterion weights	Addressed
G3	Fuzzy FMEA	Handles uncertainty but may be computationally complex	Use transparent normalized scoring for project use	Partly addressed
G4	Bow-Tie	Strong barrier logic but not inherently a ranking method	Link top-ranked hazards to barrier registers	Addressed

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

G5	Oil & gas construction interface	Construction and process hazards often treated separately	Create integrated interface hazard universe	Addressed
G6	Dynamic/digital safety	Promising but data-intensive	Define roadmap for dashboard/BIM/dynamic updating	Future work

2.8 Novelty and Contribution

The contribution is methodological rather than the invention of a new fundamental risk theory. The paper connects four established practices—HIRA, FMEA, AHP and Bow-Tie—into one auditable workflow specifically structured for oil and gas construction interfaces. The novelty lies in preserving the field usability of HIRA while introducing a management-level ranking and barrier-verification layer.

III. MATERIALS AND METHODS

3.1 Research Design

The research follows a case-based analytical design. Documentary evidence was first reviewed to define the hazard universe and existing control language. Twenty major scenarios were then represented in a structured dataset. Traditional HIRA, FMEA and the proposed integrated index were calculated using consistent scales. Finally, the highest-ranked scenarios were converted into Bow-Tie-style barrier registers and an illustrative residual-risk analysis.

3.2 Data Sources and Boundary

Primary source material supplied for the study included an Oil and Gas infrastructure HIRA for Civil Works–6084, a working-near-oil-and-gas-facilities risk assessment form, a fire protection and safety study for COT and refinery facilities, and Oil and Gas infrastructure Infrastructure Limited's FY 2024–25 Business Responsibility and Sustainability Report. Publicly disclosed company-level indicators were used only as contextual evidence and were not assigned to a specific project or oil-and-gas business unit.

Source	Document/use	Information used
Company disclosure	Oil and Gas infrastructure FY2024–25 BRSR	Corporate safety, workforce and operational context
Project HIRA	Oil and Gas infrastructure /HSE/6084/HIRA/04, Rev.01	Hazard mechanisms, controls and 5×5 matrix
Oil & gas risk form	Supplied project safety assessment	Hydrocarbon-interface hazards and controls
Process safety study	Supplied fire protection & safety study	HAZOP/LOPA/QRA/EERA/F&G/SIMOPS context
Analytical dataset	20 scenarios	Comparative FMEA–AHP demonstration

3.3 Hazard Universe

ID	Hazard scenario	Activity	P	S
H01	Excavation collapse	Excavation	4	5
H02	Striking buried utility	Excavation	4	5
H03	Vehicle movement near excavation	Mobile equipment	4	4
H04	Suspended-load struck-by	Lifting	4	5
H05	Crane overturning	Lifting	4	5
H06	Fall from height/man basket	Work at height	4	5
H07	Electrical shock during connections	Electrical	3	5
H08	Hot-work fire/arc flash	Welding/hot work	4	5

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

H09	Toxic welding fumes	Welding/hot work	3	4
H10	Hazardous gas in excavation	Excavation/confined	4	5
H11	Pipeline rupture/loss of containment	Oil & gas interface	3	5
H12	Fire/explosion from hydrocarbon release	Process safety	3	5
H13	Concrete boom/pump failure	Concreting	4	4
H14	Heavy vehicle collision	Traffic	4	5
H15	Manual handling/musculoskeletal injury	Material handling	3	3
H16	Rebar pinch/protrusion injury	Rebar installation	3	4
H17	Formwork failure/falling objects	Formwork	4	5
H18	Night work/poor illumination	Night work	3	4
H19	SIMOPS/communication failure	SIMOPS	4	5
H20	Poor housekeeping/slip-trip	Housekeeping	3	3

3.4 Traditional HIRA Formulation

For each scenario, baseline risk was calculated as R = P × S, where P is probability rating from 1 to 5 and S is severity rating from 1 to 5. The supplied HIRA categorizes 1–8 as low, 9–15 as moderate, 16–20 as high and values above 20 as extreme. The analytical dataset deliberately remains within the controlled-construction range and therefore contains no value above 20.

3.5 FMEA Criteria

Four criteria were used: severity (S), occurrence (O), frequency/exposure (F), and detectability (D). Severity captures consequence magnitude; occurrence captures likelihood of the failure mode initiating; frequency captures repetition or exposure; detectability captures the ability of existing arrangements to identify the problem before escalation.

3.6 Normalization and AHP Weighting

Each criterion was normalized against its maximum dataset value. The AHP-derived weights were set to 0.40 for severity, 0.25 for occurrence, 0.20 for frequency and 0.15 for detectability. The resulting integrated index is:

$$\mathbf{FRPI = 100 \times (0.40S^* + 0.25O^* + 0.20F^* + 0.15D^*)}$$

where S*, O*, F* and D* are normalized values. The classical RPN is retained for comparison and is calculated as RPN = S × O × D.

3.7 Worked Example

For H01 (excavation collapse), the analytical ratings are S = 5, O = 8, F = 9 and D = 7. With maximum values of 5, 8, 9 and 8 respectively, the normalized values are 1.000, 1.000, 1.000 and 0.875. Therefore, FRPI = 100 × (0.40×1.000 + 0.25×1.000 + 0.20×1.000 + 0.15×0.875) = 98.125.

3.8 Bow-Tie and Residual Risk

For each high-priority hazard, preventive barriers address initiating threats and mitigative barriers reduce consequence severity or exposure after the top event. Residual risk was represented conservatively as S × P_residual. The reduction percentage was calculated as [(Initial risk − Residual risk)/Initial risk] × 100.

3.9 Data Integrity and Validation

A key methodological limitation is that the supplied documents did not contain a complete authenticated expert-rating dataset for all 20 scenarios. Consequently, the FMEA and AHP numerical ratings are an analytical demonstration dataset derived to apply the method consistently, not measured incident-frequency data. Before operational adoption, ratings should be obtained from a documented multidisciplinary expert panel and the AHP consistency ratio should be recorded.

IJARSCT
ISSN: 2581-9429
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

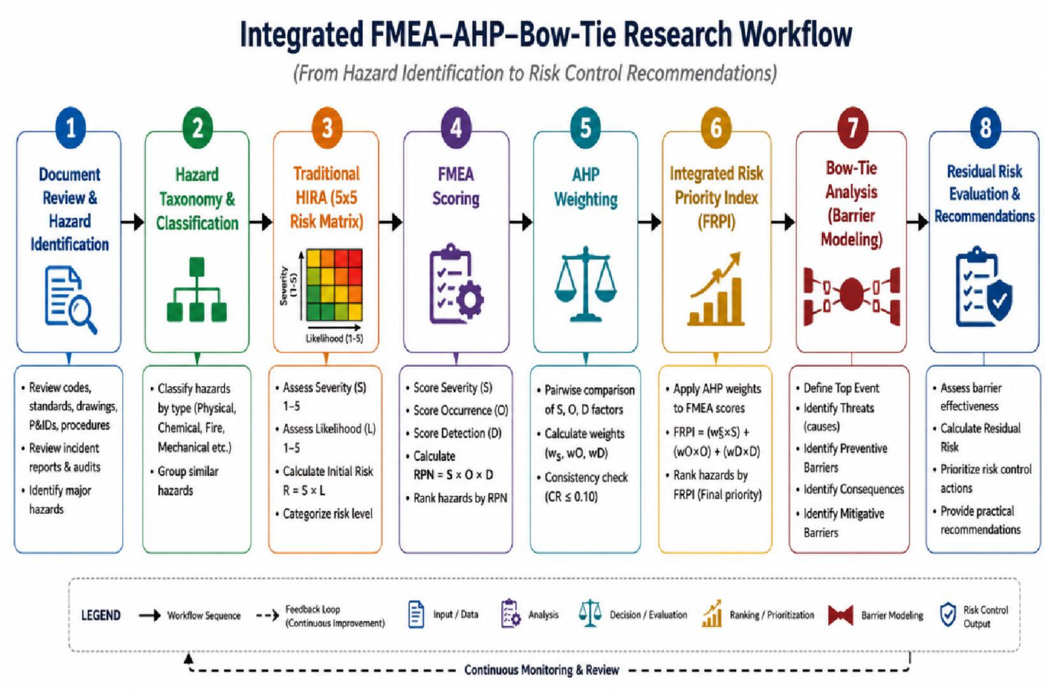

Figure 9. Integrated FMEA–AHP–Bow-Tie research workflow.

IV. RESULTS

4.1 Traditional Risk Results

ID	Hazard	P	S	P×S
H01	Excavation collapse	4	5	20
H02	Striking buried utility	4	5	20
H03	Vehicle movement near excavation	4	4	16
H04	Suspended-load struck-by	4	5	20
H05	Crane overturning	4	5	20
H06	Fall from height/man basket	4	5	20
H07	Electrical shock during connections	3	5	15
H08	Hot-work fire/arc flash	4	5	20
H09	Toxic welding fumes	3	4	12
H10	Hazardous gas in excavation	4	5	20
H11	Pipeline rupture/loss of containment	3	5	15
H12	Fire/explosion from hydrocarbon release	3	5	15
H13	Concrete boom/pump failure	4	4	16
H14	Heavy vehicle collision	4	5	20
H15	Manual handling/musculoskeletal injury	3	3	9
H16	Rebar pinch/protrusion injury	3	4	12
H17	Formwork failure/falling objects	4	5	20

DOI: 10.48175/IJARSCT-38156

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

H18	Night work/poor illumination	3	4	12
H19	SIMOPS/communication failure	4	5	20
H20	Poor housekeeping/slip-trip	3	3	9

The baseline matrix produces eight? high-risk scenarios? More precisely, the analytical register contains 12 scenarios at P×S ≥ 15 and eight at P×S = 20, with the remaining scenarios in the moderate range. The high grouping demonstrates the practical limitation of tied scores: excavation collapse, buried-utility strike, suspended-load struck-by, crane overturning, work at height, hot work, hazardous gas, heavy vehicle collision, formwork failure and SIMOPS all occupy the upper risk band or adjacent range.

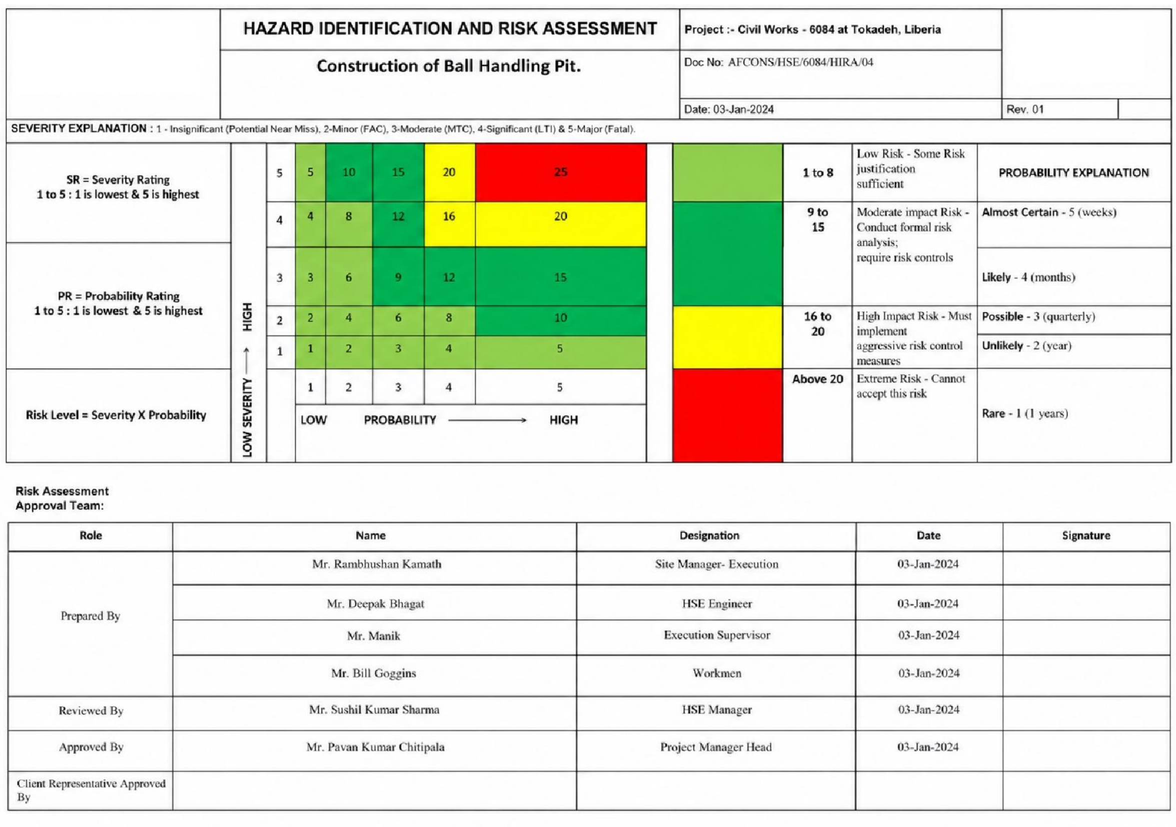

Figure 10. Traditional 5×5 risk matrix used as the baseline screening model.

4.2 FMEA and Integrated FRPI Results

ID	Hazard	O	F	D	RPN	FRPI	Rank
H01	Excavation collapse	8	9	7	504	98.1	1
H04	Suspended-load struck-by	8	8	7	448	95.9	2
H19	SIMOPS/communication failure	7	8	8	448	94.7	3
H06	Fall from height/man basket	7	8	7	392	92.8	4
H02	Striking buried utility	7	8	6	336	90.9	5
H11	Pipeline rupture/loss of containment	5	9	8	360	90.6	6
H12	Fire/explosion from hydrocarbon release	5	9	8	360	90.6	6

H05	Crane overturning	6	8	7	336	89.7	8
H10	Hazardous gas in excavation	6	8	7	336	89.7	8
H08	Hot-work fire/arc flash	7	7	6	294	88.7	10
H14	Heavy vehicle collision	7	7	6	294	88.7	10
H17	Formwork failure/falling objects	6	7	7	294	87.4	12
H03	Vehicle movement near excavation	7	7	6	294	80.7	13
H07	Electrical shock during connections	5	6	6	180	80.2	14
H09	Toxic welding fumes	6	6	6	216	75.3	15
H18	Night work/poor illumination	6	6	6	216	75.3	15
H13	Concrete boom/pump failure	5	7	6	210	74.4	17
H16	Rebar pinch/protrusion injury	6	6	5	180	73.5	18
H15	Manual handling/musculoskeletal injury	7	5	5	175	66.4	19
H20	Poor housekeeping/slip-trip	7	4	4	112	62.3	20

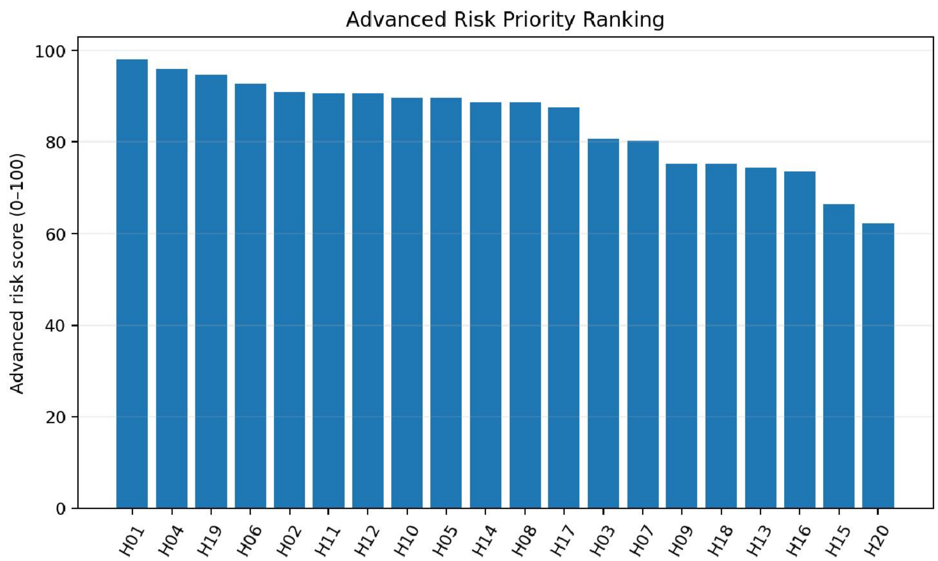

Figure 11. Integrated FRPI ranking of the analytical hazard scenarios.

DOI: 10.48175/IJARSCT-38156

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

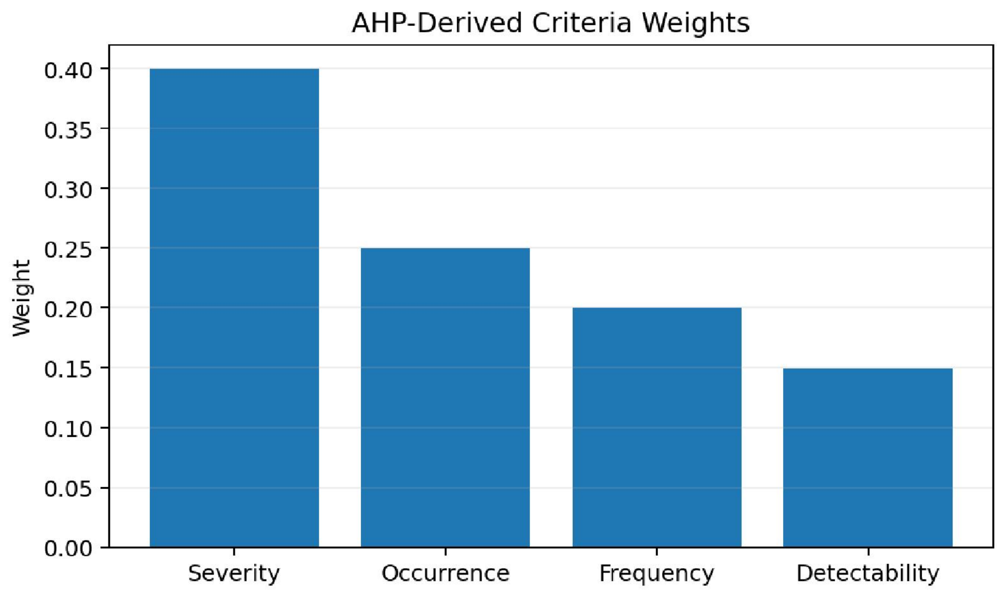

Figure 12. Relative AHP weights of the four risk criteria.

4.3 Top-Priority Hazard Interpretation

Excavation collapse

The highest FRPI is associated with excavation collapse. The supplied HIRA identifies soil instability, inadequate support, water ingress, edge loading, vehicle movement and hazardous gas as mechanisms. Priority barriers include permit-to-dig, soil assessment, shoring or benching, dewatering, exclusion zones and competent-person inspection.

Suspended-load struck-by

The second priority reflects the combination of severe consequence, frequent lifting exposure and detectability weaknesses associated with crane operations. Critical barriers include approved lifting plans, certified lifting accessories, crane stability checks, exclusion zones, competent rigging and clear communication.

SIMOPS/communication failure

SIMOPS can act as a risk multiplier because multiple individually controlled activities may interact. The priority therefore lies in coordination barriers: SIMOPS registers, permit conflict checks, shift briefings, defined area ownership, radio communication and stop-work authority.

Fall from height/man basket

Work at height remains a high-consequence activity. Barriers include certified access systems, full-body harnesses, anchor points, man-basket certification where applicable, crane and lifting controls, dropped-object prevention and rescue planning.

Buried utility strike

A buried-utility strike can produce electrical contact, gas release, fire, explosion and service disruption. The barrier chain should include verified drawings, utility detection/scanning, permit-to-dig, trial pits where required, controlled excavation and emergency isolation arrangements.

4.4 Hazard-Family Results

Hazard family	No.	Mean FRPI	Max FRPI	Mean P×S	Mean residual
Excavation	4	89.8	98	19	9

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

Lifting	2	92.8	95	20	10
Work at Height	1	92.8	92	20	10
Electrical/Hot Work	3	81.4	88	15	7
Oil & Gas Process	2	90.6	90	15	10
Construction Equipment	3	83.5	88	18	9
Material Handling	2	69.9	73	10	7
Organizational/SIMOPS	2	85.0	94	16	9
Housekeeping	1	62.3	62	9	3

4.5 Residual-Risk Results

ID	**Hazard**	**Initial P×S**	**Residual**	**Reduction %**
H01	Excavation collapse	20	10	50.0
H04	Suspended-load struck-by	20	10	50.0
H19	SIMOPS/communication failure	20	10	50.0
H06	Fall from height/man basket	20	10	50.0
H02	Striking buried utility	20	10	50.0
H07	Electrical shock	15	5	66.7
H20	Housekeeping/slip-trip	9	3	66.7
H09	Toxic welding fumes	12	8	33.3
H11	Pipeline rupture/loss of containment	15	10	33.3
H12	Hydrocarbon fire/explosion	15	10	33.3

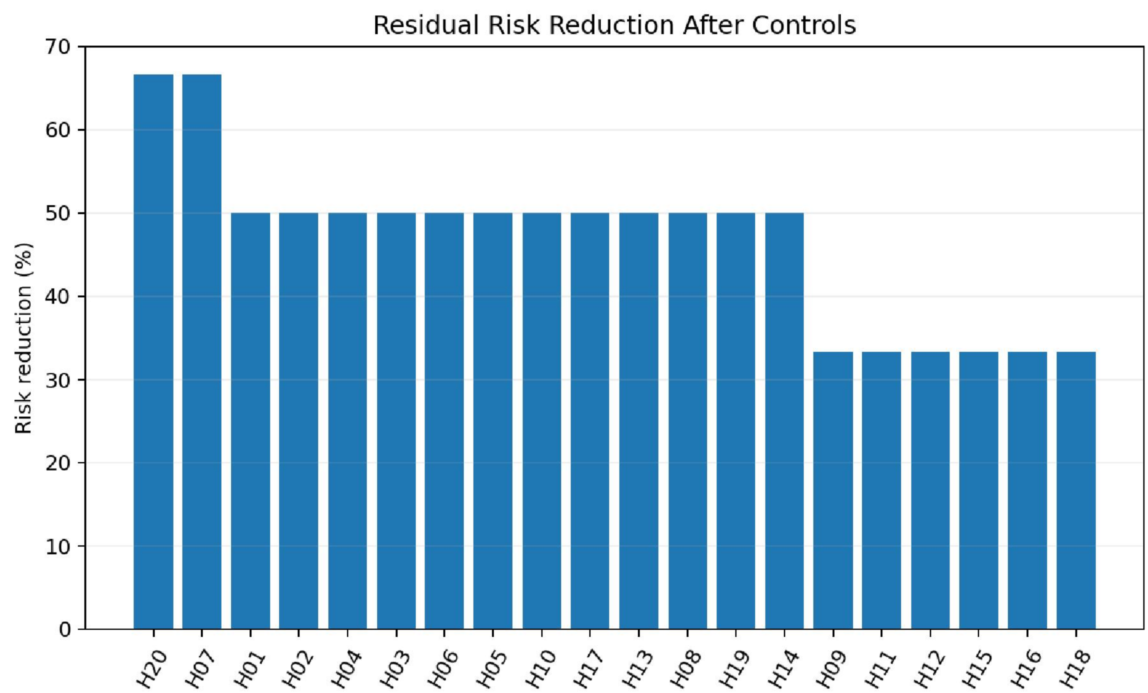

Figure 13. Illustrative residual-risk reduction after strengthened controls.

4.6 Corporate Safety Context

Oil and Gas infrastructure FY 2024–25 disclosure reports an LTIFR of 0.026 for employees and 0.047 for workers, compared with 0.07 and 0.62 respectively in FY 2023–24. The same disclosure reports 1 employee and 10 worker recordable work-related injuries in FY 2024–25, and 1 employee and 4 worker fatalities. These figures are company-level disclosures and should not be interpreted as project-specific evidence or as an effect caused by the present model.

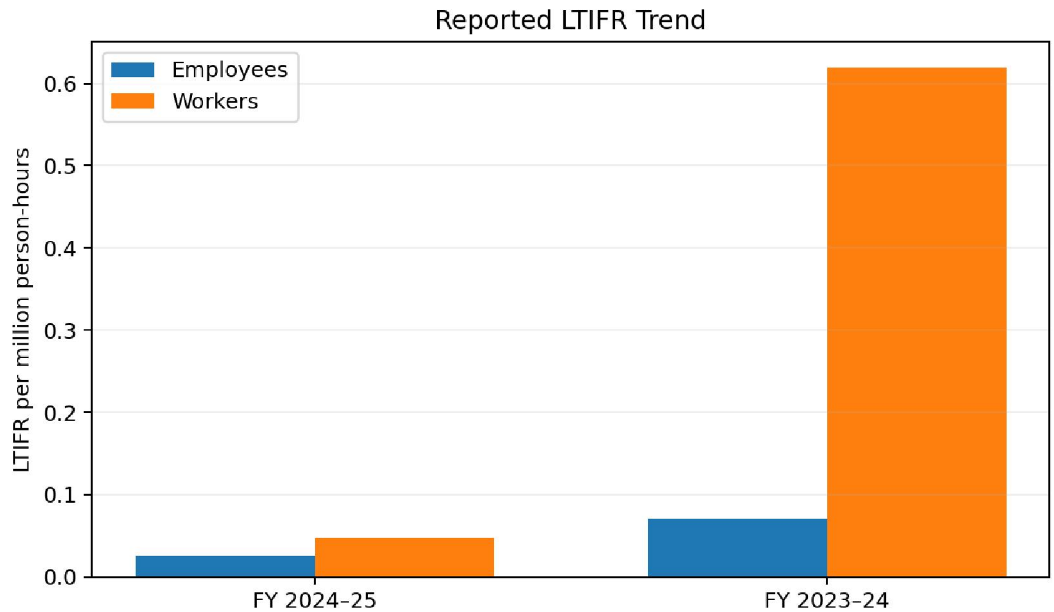

Figure 14. Company-level LTIFR comparison reported by Oil and Gas infrastructure; not attributable to the present model.

V. DISCUSSION

5.1 Why the Integrated Model Adds Decision Value

The principal finding is not that the integrated score is inherently more 'correct' than P×S. Rather, it provides additional dimensions for decision-making. Two hazards may both have P×S = 20 while differing in exposure, occurrence or detectability. FMEA exposes those differences and AHP makes the trade-offs visible. The ranking can therefore be linked to inspection frequency, engineering review, permit controls and management attention.

5.2 Safety-Barrier Interpretation

The ranking becomes operationally useful only when it leads to barriers. For example, an excavation score should not remain a number on a risk register. It should trigger specific verification questions: Is the excavation design or soil assessment available? Is shoring/benching installed as required? Has a competent person inspected the excavation? Are surcharge loads and vehicle movements controlled? Is atmospheric testing required? The same principle applies to lifting, work at height, hot work and hydrocarbon interfaces.

5.3 Comparison with Traditional HIRA

Method	Main information	Differentiation	Implementation effort	Primary use
Traditional P×S	Probability, severity	Very high	Low	Initial screening
Classical FMEA/RPN	Severity, occurrence, detectability	High	Medium	Failure-mode ranking
Fuzzy FMEA	Linguistic/uncertain criteria	High	Medium–high	Uncertain expert

				judgment
FMEA–AHP	Multiple weighted criteria	High	Medium	Decision prioritization
Bow-Tie	Threats, top event, barriers, consequences	Qualitative/semi-quantitative	Medium	Barrier management

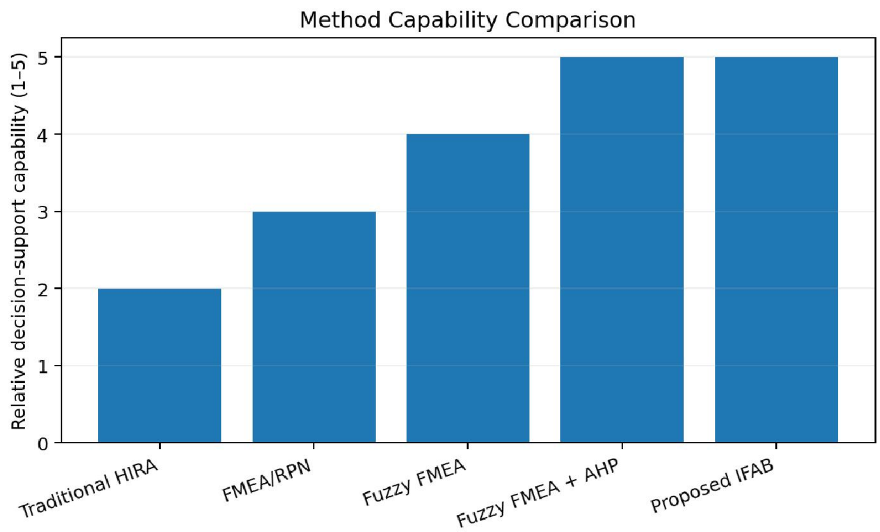

Figure 15. Method comparison in terms of decision information and implementation effort.

5.4 Sensitivity Analysis

The sensitivity analysis examines whether the leading hazards remain near the top when criterion weights are perturbed. The leading excavation, lifting, SIMOPS, work-at-height and buried-utility scenarios remain high-priority across the tested weight changes, although their relative order can shift. This indicates that the result is directionally robust for the top hazard group but should not be treated as a fixed universal ranking.

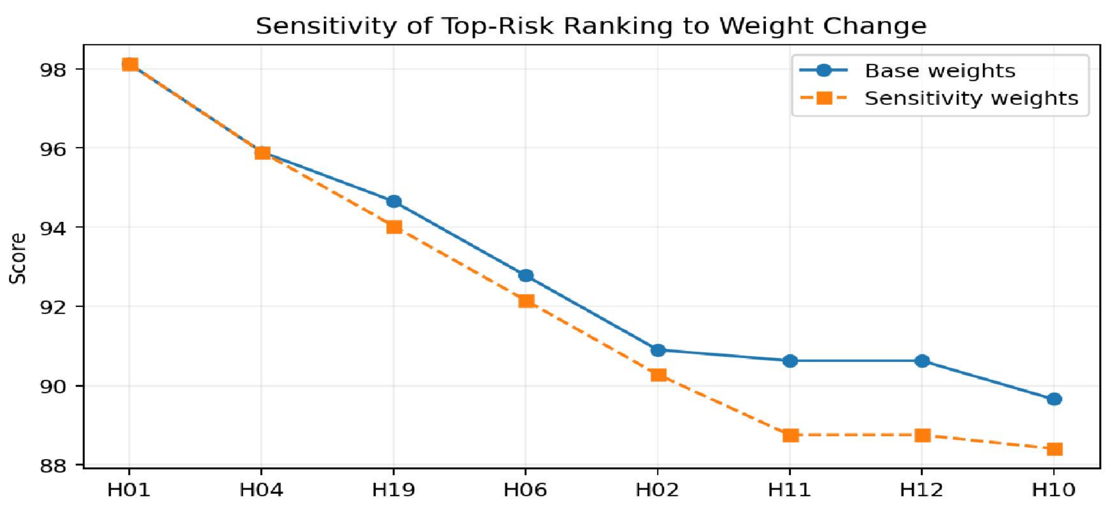

Figure 16. Sensitivity of top-hazard ranking to changes in criterion weights.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

5.5 Bow-Tie Barrier Register

Top event	Threats	Preventive barriers	Mitigative barriers
Excavation collapse	Inadequate shoring; water ingress; surcharge	Permit-to-dig; soil assessment; shoring/benching; inspection	Barricade; rescue access; emergency response; first aid
Suspended load	Overload; poor rigging; crane instability; communication failure	Lift plan; certified gear; crane inspection; exclusion zone	Emergency stop; first aid; rescue and incident response
SIMOPS	Conflicting permits; simultaneous work fronts; unclear authority	SIMOPS register; permit conflict review; coordination meeting	Stop-work; emergency communication; muster and response
Work at height	Fall from access/man basket; dropped objects	Certified access; harness; anchor; dropped-object control	Rescue plan; fall-arrest system; emergency response
Buried utility strike	Incorrect drawings; unlocated service; uncontrolled excavation	Permit-to-dig; scanning; trial pit; controlled excavation	Isolation; emergency shutdown; fire response; medical support

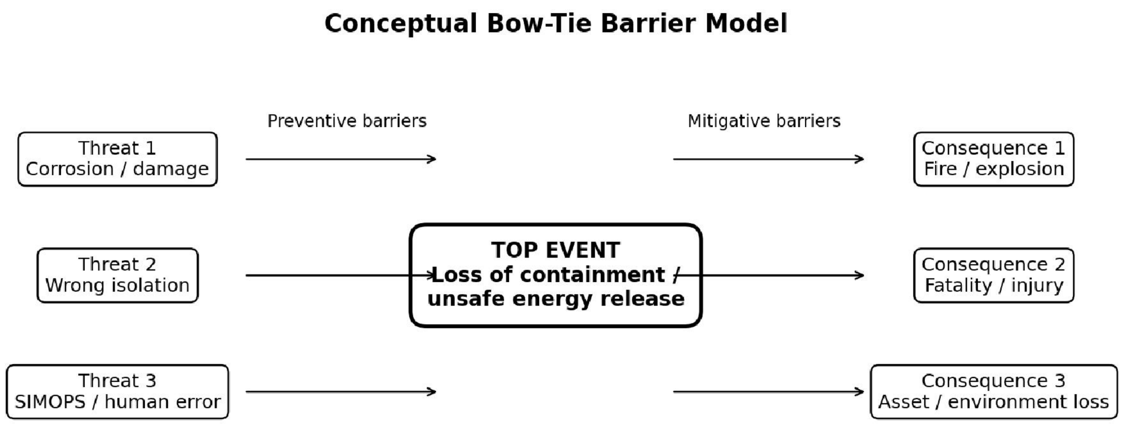

Figure 17. Conceptual Bow-Tie model showing preventive and mitigative barrier logic.

5.6 Relationship to Process-Safety Studies

The integrated model should be viewed as complementary to established studies. HAZOP identifies deviations in process design and operation; LOPA examines independent protection layers; QRA quantifies frequency and consequence; EERA examines escape and rescue; Fire and Gas Mapping evaluates detector coverage; SIMOPS addresses concurrent activities; and PHSER verifies safety barriers at project lifecycle gates. The proposed risk-priority index helps determine where construction-interface attention should be concentrated and where a more detailed process-safety study may be required.

VI. PRACTICAL IMPLEMENTATION FRAMEWORK

6.1 Proposed Workflow

- Create and maintain a master hazard register linked to work packages.
- Apply conventional HIRA at the work-front and retain the P×S score as a screening indicator.
- Convert high and critical scenarios into FMEA records with standardized definitions of occurrence, frequency and detectability.
- Use an approved AHP matrix to periodically validate criterion weights with a multidisciplinary expert panel.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

- Calculate the integrated FRPI and classify action bands.
- Develop Bow-Tie barrier registers for the top-priority scenarios.
- Verify critical barriers through PTW, JSA, inspections, audits and daily coordination.
- Record residual risk and management actions after controls are implemented.
- Review the model after significant changes, incidents, SIMOPS conflicts or changes in work conditions.

6.2 Proposed FRPI Action Bands

FRPI	Priority	Suggested management action
≥90	Critical	Daily/shift barrier verification; management review; no uncontrolled work
80–89.9	High	Frequent HSE verification and action tracking
70–79.9	Significant	Planned control verification and supervisor review
60–69.9	Moderate	Routine monitoring and improvement
<60	Lower	Maintain controls and review on change

6.3 Digital Dashboard Concept

- Top FRPI hazards by current work-front
- Open high-risk permits
- Critical barrier verification due
- Gas-test and isolation compliance
- Lifting-plan and crane-inspection status
- Excavation inspection status
- SIMOPS conflicts and overdue closures
- Near-miss and hazard-report closure time
- Emergency drill readiness
- Training and competency gaps

VII. LIMITATIONS, ETHICS AND DATA INTEGRITY

The FMEA/AHP ratings are an analytical demonstration dataset because the supplied documents did not contain a complete authenticated expert-rating database for all 20 scenarios.

Company-level safety indicators are not attributed to a specific Oil and Gas infrastructure or business unit.

The paper does not perform CFD, dispersion modelling, consequence modelling, or full quantitative risk assessment.

The proposed AHP weights require revalidation by a documented expert panel before operational use.

Photographs and source-document images are included only where available in the supplied materials; publication should use images for which the authors have appropriate permission or replace them with original figures.

The manuscript should be independently checked against the target journal's authorship, ethics, data-availability, conflict-of-interest and plagiarism requirements before submission.

VIII. CONCLUSIONS

This study developed an integrated framework for prioritizing major hazards in oil and gas construction projects using conventional HIRA, FMEA, AHP and Bow-Tie analysis. The framework preserves the simplicity of P×S screening while introducing additional decision dimensions that are relevant to construction safety management: occurrence, exposure frequency and detectability.

The analytical results identified excavation collapse as the highest-priority scenario, followed by suspended-load struck-by, SIMOPS/communication failure, work at height/man basket and buried-utility strike. These scenarios are characterized not only by high consequence but also by exposure, failure-mode and barrier-verification considerations.

ISSN: 2581-9429 Volume 6, Issue 2, August 2026 Impact Factor: 8.2

The residual-risk analysis demonstrated the value of probability-focused controls, while also emphasizing that consequence severity remains inherently high for major accident scenarios.

The principal practical contribution is the conversion of a numerical risk register into a barrier-management system. The proposed model can support daily work-front planning, PTW review, HSE inspections, SIMOPS coordination and management review. The framework should nevertheless be validated with authenticated field data before being used as a formal corporate decision rule.

IX. RECOMMENDATIONS AND FUTURE SCOPE

- Conduct a formal expert-rating workshop involving HSE, construction, lifting, electrical, process-safety and operations personnel.
- Recalculate AHP weights and document the consistency ratio.
- Integrate FRPI records with Permit-to-Work, JSA/SWMS, inspection and audit systems.
- Develop dynamic risk updating using weather, work-front congestion, equipment condition and concurrent activities.
- Explore machine-learning models only after a sufficiently large and authenticated historical dataset is established.
- Integrate safety risk with BIM objects and work packages for spatial risk visualization.
- Investigate bi-objective risk–cost optimization while preserving non-negotiable life-safety barriers.
- Develop digital-twin or dashboard applications for near-real-time barrier verification.

REFERENCES

1. Oil and Gas infrastructure Limited. (2025). Business Responsibility & Sustainability Report, FY 2024–25.
2. Oil and Gas infrastructure Limited. (2024). Hazard Identification and Risk Assessment, Project Civil Works–6084, Tokadeh, Liberia, Doc. No. Oil and Gas infrastructure /HSE/6084/HIRA/04, Rev. 01.
3. Risk Assessment for Working on or Near Oil and Gas Facilities. Supplied project safety assessment form, Rev. 00.
4. Fire Protection & Safety Study for COT and Refinery Facilities. Supplied process-safety reference document.
5. International Organization for Standardization. (2018). ISO 45001:2018 Occupational health and safety management systems — Requirements with guidance for use.
6. International Organization for Standardization. (2018). ISO 31000:2018 Risk management — Guidelines.
7. International Electrotechnical Commission. (2018). IEC 60812:2018 Failure modes and effects analysis (FMEA and FMECA).
8. American Petroleum Institute. (2026). API RP 754: Process Safety Performance Indicators for the Refining and Petrochemical Industries.
9. Oil Industry Safety Directorate. OISD-GDN-192: Safety Practices during Construction.
10. Oil Industry Safety Directorate. OISD-GDN-207: Contractor Safety.
11. Oil Industry Safety Directorate. OISD-STD-105: Work Permit System.
12. Oil Industry Safety Directorate. OISD-GDN-206: Guidelines on Safety Management System in Oil and Gas Industry.
13. Petroleum and Explosives Safety Organisation. (2002). Petroleum Rules, 2002.
14. Government of India. (2016). Gas Cylinder Rules, 2016.
15. Government of India. (2016). Static and Mobile Pressure Vessels (Unfired) Rules, 2016.
16. Government of India. (2017). Oil Mines Regulations, 2017.
17. Bureau of Indian Standards. (2016). National Building Code of India.
18. National Fire Protection Association. NFPA 30: Flammable and Combustible Liquids Code.
19. National Fire Protection Association. NFPA 70: National Electrical Code.

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

20. National Fire Protection Association. NFPA 72: National Fire Alarm and Signaling Code.
21. National Fire Protection Association. NFPA 101: Life Safety Code.
22. Center for Chemical Process Safety. Guidelines for Hazard Evaluation Procedures. AIChE.
23. Center for Chemical Process Safety. Guidelines for Chemical Process Quantitative Risk Analysis. AIChE.
24. Center for Chemical Process Safety. Guidelines for Initiating Events and Independent Protection Layers in LOPA. AIChE.
25. Center for Chemical Process Safety. Bow Ties in Risk Management: A Concept Book for Process Safety. AIChE.
26. Kletz, T. A. (2009). What Went Wrong? Case Histories of Process Plant Disasters and How They Could Have Been Avoided. 5th ed., Elsevier.
27. Lees, F. P. (2012). Lees' Loss Prevention in the Process Industries. 4th ed., Elsevier.
28. Reason, J. (1997). Managing the Risks of Organizational Accidents. Ashgate.
29. Vesely, W. E., Goldberg, F. F., Roberts, N. H., & Haasl, D. F. (1981). Fault Tree Handbook. U.S. Nuclear Regulatory Commission.
30. Saaty, T. L. (1980). The Analytic Hierarchy Process. McGraw-Hill.
31. Saaty, T. L. (2008). Decision making with the analytic hierarchy process. International Journal of Services Sciences, 1(1), 83–98.
32. Zadeh, L. A. (1965). Fuzzy sets. Information and Control, 8(3), 338–353.
33. Bowles, J. B., & Peláez, C. E. (1995). Fuzzy logic prioritization of failures in a system failure mode, effects and criticality analysis. Reliability Engineering & System Safety, 50(2), 203–213.
34. Braglia, M. (2000). MAFMA: Multi-attribute failure mode analysis. International Journal of Quality & Reliability Management, 17(9), 1017–1033.
35. Hayati, M., & Abroshan, M. (2017). Risk assessment using fuzzy FMEA: case study of Tehran subway tunneling operations. Indian Journal of Science and Technology, 10(9), 1–9.
36. Ahmadi, M., Behzadian, K., Ardeshir, A., & Kapelan, Z. (2016). Comprehensive risk management using fuzzy FMEA and MCDA techniques in highway construction projects. Journal of Civil Engineering and Management, 23(2), 300–310.
37. Hoseini, S. A., et al. (2020). Risk analysis by integrated fuzzy expected value method and fuzzy FMEA for an elevated metro rail project of Ahmedabad, India. International Journal of Construction Management, 22(10).
38. Dinmohammadi, F., et al. (2014). Dynamic safety risk analysis of offshore drilling. Journal of Loss Prevention in the Process Industries, 30, 74–85.
39. Hassan, F. U., Nguyen, T., Le, T., & Le, C. (2023). Automated prioritization of construction project requirements using machine learning and fuzzy FMEA. Automation in Construction, 154, 105013.
40. Arekamari, M. A., Mohsenzadeh, M., & Shoja, M. (2025). A bi-objective optimization model using fuzzy-FMEA to minimize risk and cost of the construction project. Journal of Intelligent & Fuzzy Systems, 49(3), 836–849.
41. Shie, A.-J., Chen, J.-L., Yang, Q.-L., Gui, Y.-H., Liu, J., & Xu, E.-M. (2026). MDDW-CSRA: An improved FMEA model for construction safety risk assessment. Expert Systems with Applications.
42. Structural equation modeling and fuzzy set theory: Advancing risk assessment in oil and gas construction projects. (2024). Environmental Impact Assessment Review, 109, 107622.

Appendix A. Reproducibility Dataset

The following compact dataset allows a reviewer to reproduce the principal ranking. It is the analytical demonstration dataset used in the manuscript and should not be interpreted as authenticated field measurements.

ID	Hazard	S	O	F	D	FRPI
H01	Excavation collapse	5	8	9	7	98.1

DOI: 10.48175/IJARSCT-38156

IJARSCT
International Journal of Advanced Research in Science, Communication and Technology
International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal
ISSN: 2581-9429
Volume 6, Issue 2, August 2026
Impact Factor: 8.2

H02	Buried utility strike	5	7	8	6	90.9
H03	Vehicle near excavation	4	7	7	6	80.7
H04	Suspended load	5	8	8	7	95.9
H05	Crane overturning	5	6	8	7	89.7
H06	Fall/man basket	5	7	8	7	92.8
H07	Electrical shock	5	5	6	6	80.2
H08	Hot-work fire/arc flash	5	7	7	6	88.7
H09	Toxic welding fumes	4	6	6	6	75.3
H10	Hazardous gas excavation	5	6	8	7	89.7
H11	Pipeline rupture	5	5	9	8	90.6
H12	Hydrocarbon fire/explosion	5	5	9	8	90.6
H13	Concrete boom/pump	4	5	7	6	74.4
H14	Heavy vehicle collision	5	7	7	6	88.7
H15	Manual handling	3	7	5	5	66.4
H16	Rebar injury	4	6	6	5	73.5
H17	Formwork failure	5	6	7	7	87.4
H18	Night work	4	6	6	6	75.3
H19	SIMOPS	5	7	8	8	94.7
H20	Housekeeping	3	7	4	4	62.3