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From Accident Causes to Risk Priorities: A Stakeholder-Based Statistical Framework for Construction Safety in India

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Abstract: ***Construction safety is a multidimensional management problem in which technical hazards interact with human, ergonomic, planning, physical, organisational and supervisory conditions. This study develops and empirically examines a stakeholder-based framework that integrates accident-cause classification, Risk Rating (RR), Failure Mode and Effects Analysis (FMEA) - based Risk Priority Number (RPN), and statistical comparison of stakeholder perceptions. A structured cross-sectional survey of 1,250 construction professionals in India was undertaken, comprising 250 architects, 250 design engineers, 250 site engineers, 250 site supervisors and 250 construction workers. Twenty-three accident causes were organised into five domains—ergonomic, planning, physical, person and management activities—and evaluated against eight accident-risk categories. The overall RR ranking placed slips/trips/falls first (14.77), followed by struck by objects (14.23), falling from height (13.00), caught in between (12.17), collapses/cave-ins (9.60), faulty tools (7.95), electrocution (6.23), and fire/explosions (3.75). Stakeholder-specific RPN profiles and cause-wise statistical tests indicated substantial differences for many cause–risk combinations, while a small number of combinations showed non-significant differences. The findings demonstrate that construction risk cannot be understood adequately from a single stakeholder or a single risk score. This study contributes an integrated decision-support framework that connects cause identification, stakeholder perception, risk prioritisation, statistical evidence and targeted controls, with particular relevance to the Indian construction context.***

Keywords: Construction Safety, Accident Causation, Stakeholder Perception, Risk Rating, FMEA, RPN, t-test, Safety Management

1. Introduction

The construction industry is indispensable to economic development, infrastructure provision and urban transformation, yet it remains characterised by temporary and continuously changing workplaces, multiple trades, heavy equipment, work at height, material handling, excavation, electrical systems and close interaction between people and machines. The International Labour Organization (2022)[1] identifies construction as an occupational sector in which safety and health risks are particularly significant because hazards evolve across project phases. The dynamic nature of construction means that safety performance depends not only on workers' behaviour but also on design decisions, planning, supervision, resource allocation, site conditions and organisational practices.

Accident causation research has progressively moved from worker-error explanations toward systemic interpretations. Abdelhamid and Everett (2000)[2] emphasised root-cause identification rather than merely recording the immediate event, while Haslam et al. (2005)[3] demonstrated that construction accidents arise through interacting organisational, project, workplace and individual factors. Reviews (2021)[4] of unsafe behaviour likewise show that worker actions are embedded within the work environment and shaped by management, supervision, experience and perceived pressures (Choudhry & Fang, 2008[5]; Khosravi et al., 2014)[6].

Stakeholder perception constitutes a second important dimension. Architects, designers, engineers, supervisors and workers occupy different positions in the construction system and consequently have different exposure, responsibilities and information. Zhao et al. (2016)[7] provided empirical evidence that construction stakeholders can differ systematically in their perceptions of risk. Such differences matter because risk assessment is ultimately translated into decisions about design, planning, resource allocation, supervision, and worker protection.

Indian research, Choudhry, R. M., Fang, D., & Mohamed, S. (2007)[8] continues to identify challenges involving management commitment, training, communication, PPE, supervision, safety culture and compliance. A systematic review of Construction-worker health and safety research in India (2021)[9] found strong concentration on safety management, safety climate, safety performance, musculoskeletal disorders and behaviour-based safety, while also identifying theoretical and methodological gaps. More recent studies Chellappa, V., Al-Bayati, A. J., Selín, J., & Suhányiová, A. (2026)[10] continue to identify fall protection, training and management practices as important priorities.

Against this background, the present study proposes and tests a stakeholder-based statistical framework that moves from accident causes to risk priorities. It combines 23 causes, five causal domains, eight accident categories, five stakeholder groups, RR, FMEA/RPN and inferential testing. The central premise is that a useful safety-management system should identify not only what hazards are considered important, but also where stakeholder perceptions converge or diverge and where preventive resources should be concentrated.

2. Literature Review

2.1 Construction accident causation

Construction accident causation is increasingly understood as a layered process rather than a single-event failure. Abdelhamid and Everett (2000)[2] distinguished unsafe conditions, unsafe decisions and unsafe acts as root contributors. Haslam et al. (2005)[3] subsequently demonstrated that accident causes span project and organisational levels, including site conditions, worker factors, equipment/material factors, supervision and project management. This systemic view supports the present classification of causes into ergonomic, planning, physical, person and management domains.

2.2 Ergonomic and behavioural factors

Repetitive handling, heavy lifting, prolonged postures; fatigue, long working hours and monotony can reduce physical and cognitive capacity and influence safety behaviour Barman, S., et al. (2024)[11]. Choudhry and Fang (2008)[5]argued that unsafe behaviour should be examined within its work context rather than attributed simply to individual negligence. Khosravi et al. (2014)[6] similarly identified organisational, individual and environmental contributors. These findings justify incorporating ergonomic and person-related causes alongside technical hazards.

2.3 Planning, management and safety climate

Planning decisions concerning sequencing, resources, schedules, design and work assignments can create or remove hazards before physical work begins. Management commitment, supervisor safety roles, safety rules, procedures, training and worker responsibility are recognised dimensions of construction safety climate Choudhry, R. M., Fang, D., & Lingard, H. (2009)[12]. Alruqi et al. (2018)[13] showed through meta-analysis that safety-climate dimensions are associated with construction safety performance. Samanta, S., & Gochhayat, J. (2023)[14] Indian evidence also indicates that management involvement and safety training influence safety performance and compliance.

2.4 Physical and environmental hazards

Construction sites are characterised by rapidly changing physical conditions involving material quality, site nature, climate, noise, vibration and exposure to hazardous materials. Forteza et al. (2016)[15] argued that construction-site risk should be understood as an integrated characteristic of a temporary workplace rather than as a collection of independent hazards. This perspective supports an assessment model that links physical conditions to organisational and human factors.

2.5 Stakeholder risk perception

Risk is partly technical and partly perceptual. Zhao et al. (2016)[8] found measurable differences among construction stakeholders, demonstrating that architects, engineers and other project participants may evaluate likelihood differently. A recent systematic review of hazard recognition and risk perception research (2025)[16] confirms that risk perception is closely related to hazard recognition, safety behaviour and safety-management strategies. Consequently, stakeholder diversity should be incorporated into risk assessment rather than averaged away without analysis.

2.6 FMEA and Risk Priority Number

FMEA is a structured technique for identifying potential failure modes, assessing their consequences and prioritising corrective action Juan, Y.-K., Sheu, U.-Y., & Chen, K.-S. (2023)[17]. Traditional RPN is calculated as occurrence × severity × detection. Its practical advantages include simplicity, transparency and ease of communication. However, equal weighting of the three dimensions and rank-equivalence limitations mean that RPN should not be treated as a complete representation of risk. Recent construction studies have therefore explored statistical, fuzzy and hybrid approaches. The present study retains conventional RPN because the objective is an interpretable empirical prioritisation framework, while explicitly recognising these limitations.

2.7 Research gap and novelty

Four gaps motivate the study.

First, many investigations focus on individual accident causes or hazard groups rather than integrating multiple causal domains.

Second, stakeholder differences are often examined without linking them to a complete accident-risk prioritisation system.

Third, RR and FMEA/RPN are frequently used independently.

Fourth, India needs more multi-stakeholder empirical evidence for proactive safety management.

The novelty lies in connecting:
cause identification → domain classification → RR/RPN assessment → stakeholder comparison → significance testing → targeted control selection → monitoring and review.

3. Conceptual Framework and Hypotheses

The framework contains four interconnected elements: (i) 23 accident causes, (ii) five causal domains (table 1), (iii) eight accident-risk categories, and (iv) a management pathway connecting RR, RPN, stakeholder comparison, statistical testing and targeted intervention (figure 1).

The first: Twenty three accident causes are: Repetitive handling, Heavy lifting, prolonged single position, Carelessness, Negligence, Structure and design, Project Schedule, Inadequate Budget, Material Quality, Site nature, Climate, Noise, Vibration, Exposure to materials, Long working hours, Tight Deadlines, Monotony, Fatigue, Inter-personal relationships, Work assignments, Vendor miss-

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management, Untrained and incompetent workers, Ineffective supervision and examination.

The Second: The classification of accident causes into five domains as shown in the table 1.

Table 1: Classification of accident causes into five domains

Cause domain	No. of causes	Share
Ergonomic activities	3	13%
Planning activities	5	22%
Physical activities	6	26%
Person activities	5	22%
Management activities	4	17%
Total	23	100%

The third: The eight accident-risk categories are: falling from height; slips, trips and falls; struck by objects; electrocution; caught in between; faulty tools; collapses/cave-ins; and fire/explosions.

The fourth: The stakeholder-based construction accident risk assessment framework is shown in fig. 1.

Stakeholder-Based Construction Accident Risk Assessment Framework

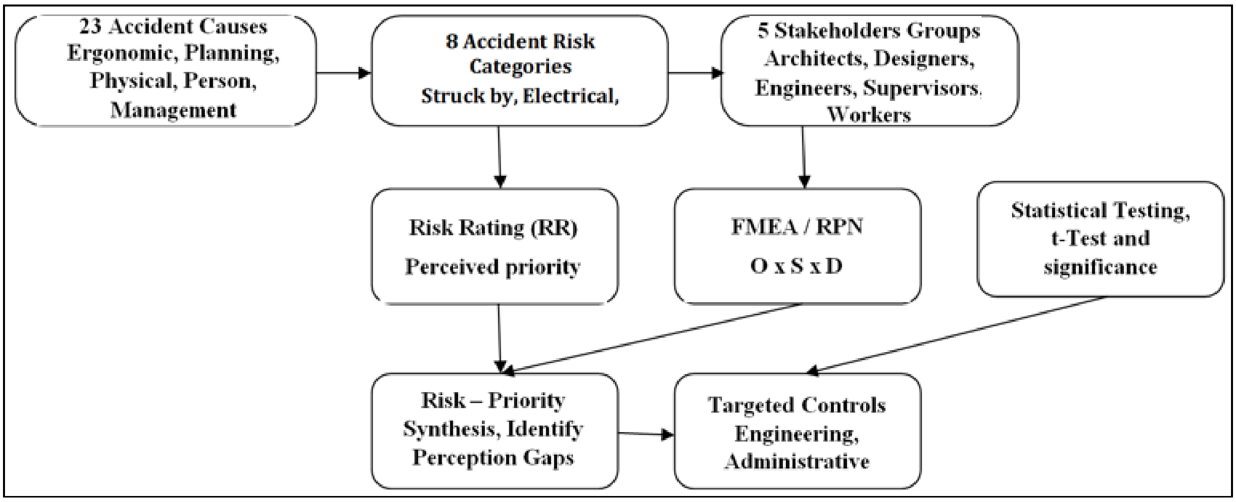

Figure 1: Stakeholder-based construction accident risk assessment framework
Source: Primary data

Research hypotheses

- H1: Stakeholder perceptions of ergonomic accident causes differ significantly among construction stakeholder groups.
- H2: Stakeholder perceptions of planning-related accident causes differ significantly among construction stakeholder groups.
- H3: Stakeholder perceptions of physical accident causes differ significantly among construction stakeholder groups.
- H4: Stakeholder perceptions of person-related accident causes differ significantly among construction stakeholder groups.
- H5: Stakeholder perceptions of management-related accident causes differ significantly among construction stakeholder groups.
- H6: Stakeholder perceptions differ significantly across the eight major construction accident-risk categories.

4. Methodology

4.1 Research design and sample

A quantitative cross-sectional survey design was adopted. Purposive sampling was used because respondents were required to have direct involvement in construction planning, design, supervision or execution. The sample comprised 1,250 respondents, equally distributed among five stakeholder groups.

Table 2: Sample composition

Stakeholder group	Sample	Share
Architects	250	20%
Design/Design Engineers	250	20%
Site Engineers	250	20%
Site Supervisors	250	20%
Construction Workers	250	20%
Total	1250	100%

4.2 Measurement and analytical procedure

The questionnaire assessed 23 accident causes and eight accident-risk categories. A 10-point FMEA rating approach was used for occurrence (O), severity (S) and detection (D).
$RPN = O \times S \times D$

Risk Rating (RR) was additionally used to represent perceived relative importance of each accident category. Inferential analysis used t-tests with $\alpha = 0.05$. Because the supplied material does not contain complete original degrees of freedom, standard errors or software output, the reported test statistics and p-values are reproduced without reconstructing missing statistics.

5. Results

5.1 Overall accident-risk ranking

Table 3: Overall ranking of construction accident risks

Rank	Accident category	Mean RR	Risk interpretation
1	Slips, Trips and Falls	14.77	Very High Risk
2	Struck by Objects	14.23	Very High Risk
3	Falling from Height	13.00	High Risk
4	Caught in Between	12.17	High Risk
5	Collapses/Cave-ins	9.60	Moderate Risk
6	Faulty Tools	7.95	Moderate Risk
7	Electrocution	6.23	Low–Moderate Risk
8	Fire/Explosions	3.75	Low Risk

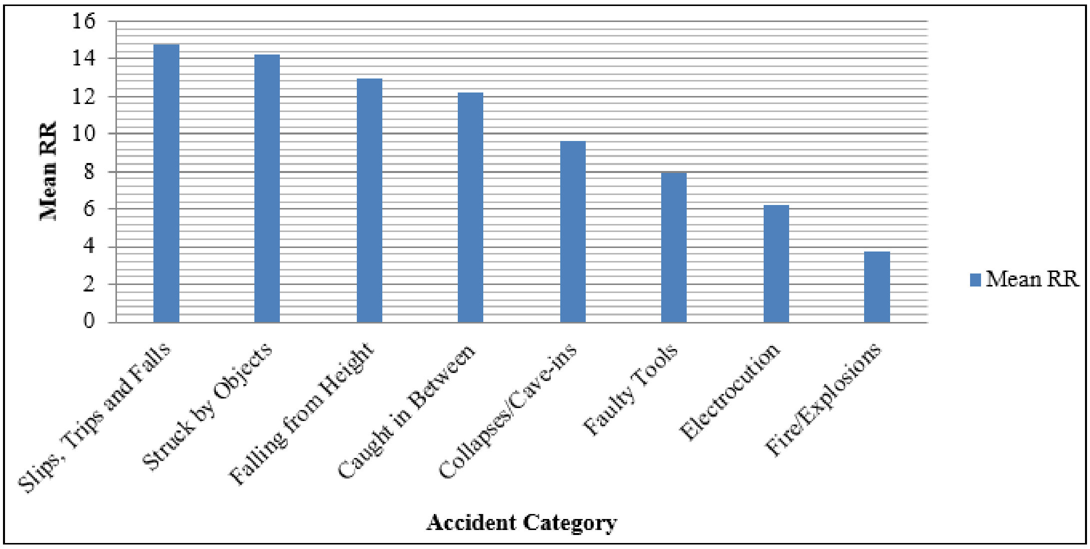

Figure 2: Overall construction accident-risk ranking based on Mean RR.

The overall risk-rating analysis indicates a clear hierarchy among the eight construction accident categories. Slips, Trips and fall occupy the first rank with the highest Mean RR of 14.77, classified as Very High Risk. This finding indicates that routine movement-related hazards represent the most prominent perceived accident risk among the assessed construction activities. The second-ranked category, Struck by Objects, records a Mean RR of 14.23, also falling within the Very High Risk category, highlighting the importance of hazards associated with falling, moving, or improperly handled materials and objects.

Falling from Height ranks third with a Mean RR of 13.00, indicating a High Risk, followed by Caught in Between with a Mean RR of 12.17, also classified as High Risk. These results demonstrate that both work-at-height activities and entrapment-related situations remain major safety concerns requiring systematic preventive measures.

The next group comprises Collapses/Cave-ins (Mean RR = 9.60) and Faulty Tools (Mean RR = 7.95), both classified as Moderate Risk. Although their rankings are lower than the first four categories, their moderate risk levels indicate that they cannot be neglected in construction safety planning. Electrocution, with a Mean RR of 6.23, is classified as Low–Moderate Risk, while Fire/Explosions records the lowest Mean RR of 3.75 and is classified as Low Risk.

Overall, the ranking demonstrates that routine site-movement hazards, object-related hazards, work-at-height hazards, and entrapment hazards constitute the principal accident-risk priorities in the study. The difference between the highest-ranked risk (14.77) and the lowest-ranked risk (3.75) further suggests considerable variation in perceived accident risk across hazard categories. Therefore, safety management interventions should be risk-prioritised, with greater attention and resources directed initially toward slips/trips/falls, struck-by objects, falling from height, and caught-in-between hazards, while maintaining appropriate preventive controls for the lower-ranked categories.

5.2 Stakeholder-wise risk perception

Table 4: Mean Risk Rating by stakeholder group

Accident category	Architects	Designers	Site Engineers	Site Supervisors	Construction Workers	Overall Mean
Falling from Height	14.31	13.85	12.46	13.62	10.77	13.00
Slips, Trips and Falls	15.69	15.54	14.23	12.38	16.00	14.77
Struck by Objects	11.08	14.23	15.38	16.31	14.15	14.23
Electrocution	5.54	6.31	8.54	5.46	5.31	6.23
Caught in Between	10.77	13.31	11.85	14.69	10.23	12.17
Faulty Tools	8.08	7.92	8.54	8.31	6.92	7.95
Collapses/Cave-ins	—	—	—	—	—	9.60
Fire/Explosions	—	—	—	—	—	3.75

Table 4 reveals substantial variation in the perception of construction accident risks among the five stakeholder groups, namely architects, designers, site engineers, site supervisors and construction workers. The variation suggests that professional role; level of site involvement and direct exposure to construction activities may influence how different stakeholders perceive accident risks.

For Falling from Height, architects report the highest Mean RR (14.31), followed by designers (13.85) and site supervisors (13.62), whereas construction workers record the lowest rating (10.77). Site engineers report 12.46. This pattern indicates that the perceived seriousness of work-at-height hazards is higher among the professional and supervisory groups than among workers in the present dataset.

For Slips, Trips and fall, construction workers give the highest rating (16.00), followed by architects (15.69) and designers (15.54). Site engineers record 14.23, while site supervisors report the lowest value (12.38). The particularly high rating among construction workers is noteworthy because they have direct and frequent exposure to movement-related site conditions. The overall Mean RR of 14.77, as shown in Table 3, consequently places this category as the highest-ranked accident risk.

A different pattern is observed for Struck by Objects. Site supervisors report the highest Mean RR (16.31), followed by site engineers (15.38), construction workers (14.15) and designers (14.23), while architects report the lowest rating (11.08). The high ratings among site supervisors and site engineers may reflect their direct involvement in coordinating site activities, material movement and work operations. The overall Mean RR of 14.23 places this category second in the overall risk ranking.

For Electrocution, all stakeholder groups report comparatively lower ratings. Site engineers provide the highest Mean RR (8.54), followed by designers (6.31), architects (5.54), site supervisors (5.46) and construction workers (5.31). Despite differences between stakeholder groups, the overall Mean RR of 6.23 indicates a Low–Moderate Risk classification.

The pattern for Caught in Between also demonstrates stakeholder variation. Site supervisors record the highest Mean RR (14.69), followed by designers (13.31), site engineers (11.85), architects (10.77) and construction workers (10.23). The overall Mean RR of 12.17 places this accident category within the High Risk level. The comparatively high perception among site supervisors is particularly notable because their responsibilities involve close monitoring and coordination of ongoing site operations.

For Faulty Tools, the ratings are relatively consistent among architects (8.08), designers (7.92), site engineers (8.54) and site supervisors (8.31), while construction workers report the lowest Mean RR (6.92). The overall Mean RR of 7.95 indicates a Moderate Risk level.

The table does not provide stakeholder-wise values for Collapses/Cave-ins and Fire/Explosions, with the entries represented by dashes. Therefore, no stakeholder-specific comparison can be made for these two categories from Table 4. Their overall Mean RR values (9.60 and 3.75, respectively) are available from the overall analysis, but these should not be attributed to any particular stakeholder group.

Overall inference

The findings demonstrate that stakeholder risk perception is not uniform across accident categories. Architects tend to assign relatively high ratings to falling from height and slips/trips/falls, while site supervisors and site engineers show particularly high perceptions for struck-by-object and caught-in-between hazards. Construction workers record the highest stakeholder-specific rating for slips, trips and falls (16.00), but comparatively lower ratings for falling from height, electrocution, caught-in-between and faulty tools.

Thus, the results provide an important justification for the subsequent t-test analysis. The observed differences in Mean RR indicate potential stakeholder-level divergence that requires inferential testing to determine whether these differences are statistically significant. Consequently, Table 4 establishes the descriptive foundation for the cause-wise and risk-wise t-test analysis presented in the subsequent tables.

5.3 Stakeholder-specific average RPN profiles

Table 5: Stakeholder-specific average RPN profiles

Stakeholder	Height	Slips	Struck	Electro	Caught	Faulty	Collapse	Fire
Architects	392	384	336	245	280	343	294	140
Design Engineers	432	384	360	280	280	294	392	128
Site Engineers	384	384	336	336	336	343	294	128
Site Supervisors	392	448	343	343	343	343	343	112
Construction Workers	252	294	294	252	294	294	343	63

Table 5 presents the stakeholder-specific average Risk Priority Number (RPN) profiles across the eight major construction accident categories. The results demonstrate clear differences in the priorities assigned by architects, design engineers, site engineers, site supervisors and construction workers, indicating that risk prioritisation varies according to stakeholder role and proximity to construction activities.

Among the stakeholders, design engineers record the highest RPN for Falling from Height (432), suggesting that work-at-height hazards are perceived as particularly critical from the design and engineering perspective. Architects record an RPN of 392, while site supervisors also record 392. Site engineers report 384, whereas construction workers record the lowest value of 252. This variation indicates a notable difference between professional/supervisory perceptions and the perception of workers regarding the priority assigned to height-related risks.

For Slips, Trips and fall, the highest RPN is recorded by site supervisors (448), the highest individual RPN value in the entire table. This indicates that site supervisors consider movement-related hazards to be an especially important safety priority. Architects and design engineers each record 384, followed by site engineers (384) and construction workers (294). The particularly high supervisory RPN is consistent with the direct responsibility of supervisors for monitoring day-to-day site activities.

In the case of Struck by Objects, design engineers record the highest RPN (360), followed by site supervisors (343), while architects and site engineers record 336 each. Construction workers report a comparatively lower RPN of 294. This pattern suggests that object-related hazards are viewed as a substantial priority by those involved in design, planning and site coordination.

For Electrocution, site supervisors record the highest RPN (343), followed by site engineers (336), design engineers (280), construction workers (252) and architects (245). Although electrocution received a relatively lower Mean RR in the overall risk-rating analysis, its RPN profile demonstrates that the incorporation of occurrence, severity and detection dimensions can produce a different prioritisation pattern across stakeholder groups.

The Caught in Between category records an RPN of 343 for site supervisors and 336 for site engineers, while architects and design engineers each record 280 and construction workers record 294. The relatively high values among site-based supervisory and engineering groups indicate that entrapment hazards warrant particular attention during site operations.

For Faulty Tools, site supervisors record the highest RPN (343), followed by architects (343), site engineers (343), while design engineers and construction workers record 294 each. The relatively consistent RPN values among the first three professional groups indicate broad recognition of faulty tools as a safety concern, although its priority differs from that suggested by the overall Mean RR.

For Collapses/Cave-ins, design engineers record the highest RPN (392), whereas construction workers record 343, and architects, site engineers and site supervisors record 294, 294 and 343, respectively. The comparatively high value among design engineers may indicate greater emphasis on structural stability and collapse-related consequences within the design perspective.

Finally, Fire/Explosions have the lowest RPN values across all stakeholder groups, ranging from 63 among construction workers to 140 among architects. Architects report the highest RPN (140), followed by design engineers and site engineers (128 each), site supervisors (112) and construction workers (63). This finding is consistent with the comparatively low overall risk classification of Fire/Explosions observed in the overall risk-ranking analysis.

Overall inference

The RPN profiles demonstrate that no single accident category is assigned the same level of priority by all stakeholder groups. Site supervisors consistently report high priorities for several operational hazards, particularly Slips, Trips and fall (448), Electrocution (343), Caught in Between (343) and Faulty Tools (343). Design engineers assign particularly high priorities to Falling from Height (432), Struck by Objects (360) and Collapses/Cave-ins (392). Site engineers show relatively high priorities for Electrocution and Caught in Between (336 each), while construction workers generally report lower RPN values across several categories.

The findings therefore demonstrate that RPN-based safety prioritisation is stakeholder-sensitive. The highest RPN values do not necessarily correspond directly with the overall Mean RR ranking, highlighting the value of considering multiple dimensions of risk rather than relying solely on perceived risk rating. Most importantly, these descriptive differences provide the basis for the subsequent t-test analysis, which is required to establish whether the observed differences in risk prioritisation between stakeholder groups are statistically significant.

A particularly important finding is the contrast between Mean RR and RPN. While Slips, Trips and fall have the highest overall Mean RR (14.77), the highest individual stakeholder RPN is 448 for Slips, Trips and fall among site supervisors, whereas falling from height reaches 432 among design engineers. This reinforces the argument that construction safety interventions should be stakeholder-specific and hazard-specific, rather than based on a single aggregated risk score.

5.3 Cause-wise statistical analysis

Table 6: Reported t-test values for stakeholder differences

Cause	Height	Slips	Struck	Electro	Caught	Faulty	Collapse	Fire
Repetitive handling	4.274	5.701	5.615	2.236	3.301	7.741	5.019	2.712
Heavy lifting	5	4.846	4.757	3.13	3.413	4.1	14	3.029
Prolonged single position	4.257	4.3	6.708	2.982	2.123	3.944	3.28	5.715
Carelessness	4.529	6.246	12.147	12.364	18.779	8.615	14.143	5.876
Negligence	5.751	14.143	12.364	18.779	17.963	8.091	9.889	5.013
Structure and design	4.52	6.482	6.068	4.635	5.286	4.899	4.237	4.216
Project Schedule	7.75	5.241	5.327	4.325	2.994	4.913	13.88	6.5
Inadequate Budget	3.965	6.771	7.364	4.077	3.283	6.091	7.926	4.494
Material Quality	4.635	8.5	5.308	7.902	7.233	8.944	24	12.649
Site nature	7.632	5.327	4.041	6	4.333	3.9	3.268	3.415
Climate	3.83	5.85	3.737	4	3.727	5.286	3.841	3.674

Noise	5.729	11	5.013	8.573	3.81	6.882	3.055	2.34
Vibration	4.468	11.952	14.697	3.475	19	7.738	14.697	14.697
Exposure to materials	5.013	6.708	3.902	6.328	9	11	2.638	11.677
Long working hours	9.892	10.113	6.046	5.286	7.233	21	3.792	—
Tight Deadlines	5.917	4.593	6.029	3.465	6.755	4.844	13.88	3.792
Monotony	21	6	17.963	7.695	7.738	7.757	4.518	5.013
Fatigue	10.113	6.39	8.525	7.571	79	10.156	3.589	3.521
Inter-personal relationships	5.25	3.301	2.123	2.994	2.135	6.5	4.472	3.255
Work assignments	9.662	7.926	17.963	3.796	11	7.738	12.649	4.692
Vendor miss-management	2.24	6.403	5.715	9.594	8.045	7.738	11.225	14.697
Untrained and incompetent workers	5.549	8.091	9.707	11.677	11.677	11.677	8.663	7.059
Ineffective supervision and examination	6.186	8.317	5.578	12.124	3.852	11	11	4.867

Table 6 presents the reported t-test values for stakeholder differences across 23 accident causes and eight construction accident-risk categories. The results indicate considerable variation in the magnitude of the reported test statistics across cause–risk combinations, suggesting that stakeholder perceptions of accident causation differ according to both the underlying cause and the type of accident risk.

The results for the ergonomic causes show generally substantial test statistics across the accident categories. Repetitive handling records t-values ranging from 2.236 to 7.741, while heavy lifting ranges from 3.029 to 14.000, with the highest value occurring for Collapses/Cave-ins. Prolonged single position produces values between 2.123 and 6.708, with the highest value for Struck by Objects. These findings indicate that ergonomic conditions do not generate a uniform pattern of stakeholder differences across accident categories.

The person-related causes—carelessness and negligence—show particularly pronounced differences for selected accident risks. Carelessness records a t-value of 18.779 for Caught in Between, 14.143 for Collapses/Cave-ins, 12.364 for Electrocution, and 12.147 for Struck by Objects. Similarly, negligence records high values of 18.779 for Electrocution, 17.963 for Caught in Between, 14.143 for Slips, Trips and fall, and 12.364 for Struck by Objects. These results suggest that stakeholder perceptions associated with human and behavioural causes vary strongly for particular accident mechanisms.

Among the planning-related causes, Structure and Design produces relatively moderate values, ranging from 4.216 to 6.482. Project Schedule, however, reaches 13.880 for Collapses/Cave-ins, indicating a particularly strong stakeholder difference for this combination. Inadequate Budget records values between 3.283 and 7.926, suggesting comparatively moderate variation across the accident categories.

Material Quality produces one of the most prominent results in the entire table, with a t-value of 24.000 for Collapses/Cave-ins and 12.649 for Fire/Explosions. It also records relatively high values for Faulty Tools (8.944) and Electrocution (7.902). This pattern highlights material quality as an important cause requiring differentiated attention, particularly in relation to structural failure and fire-related risks.

The physical/environmental causes also demonstrate substantial variation. Site Nature records its highest value for Falling from Height (7.632), while Climate remains comparatively moderate across the eight accident categories. Noise produces a high t-value of 11.000 for Slips, Trips and fall and 8.573 for Electrocution. Vibration is particularly noteworthy, recording 19.000 for Caught in Between, 14.697 for Struck by Objects, Collapses/Cave-ins and Fire/Explosions, and 11.952 for Slips, Trips and fall. These results indicate that physical working conditions may be perceived differently depending on the accident mechanism under consideration.

Several work-organisation and human-condition variables demonstrate high test statistics. Long Working Hours records 21.000 for Faulty Tools, while Monotony records 21.000 for Falling from Height and 17.963 for Struck by Objects. Fatigue produces the highest reported t-value in the entire table—79.000 for Caught in Between—followed by 10.156 for Faulty Tools and 10.113 for Falling from Height. These exceptionally large reported values identify fatigue and work-organisation factors as particularly important areas for further statistical examination.

The results for Inter-personal Relationships are comparatively lower, with values ranging from 2.123 to 6.500, whereas Work Assignments show considerably higher values, including 17.963 for Struck by Objects, 12.649 for Collapses/Cave-ins, and 11.000 for Caught in Between. Vendor Miss-management reaches 14.697 for Fire/Explosions and 11.225 for Collapses/Cave-ins, while Untrained and Incompetent Workers produces relatively high values for Electrocution, Caught in Between and Faulty Tools (11.677 each). Ineffective Supervision and Examination reaches 12.124 for Electrocution and 11.000 for both Faulty Tools and Collapses/Cave-ins.

Overall inference

Overall, Table 6 demonstrates that stakeholder differences are cause-specific as well as accident-specific. The highest reported test statistics are concentrated in particular cause–risk combinations rather than being evenly distributed across all eight accident categories. The most prominent combinations are:

- Fatigue → Caught in Between : t = 79.000
- Material Quality → Collapses/Cave-ins : t = 24.000
- Long Working Hours → Faulty Tools : t = 21.000
- Monotony → Falling from Height : t = 21.000
- Vibration → Caught in Between : t = 19.000
- Carelessness → Caught in Between : t = 18.779
- Negligence → Electrocution : t = 18.779

These findings suggest that fatigue, material quality, working hours, monotony, vibration, carelessness and negligence represent particularly important areas of stakeholder differentiation in the reported analysis.

However, the magnitude of a t-statistic should not itself be interpreted as an effect size. The present interpretation is restricted to the reported test statistics because the supplied analysis does not provide the complete degrees of freedom and standard errors needed for independent verification of the tests. Accordingly, the next table containing the significance values (p-values) is essential for determining which of these observed stakeholder differences are statistically significant at α = .05.

Thus, Table 6 establishes the magnitude and pattern of the reported stakeholder differences, while Table 7 provides the statistical significance of those differences. Together, the two tables provide the principal inferential basis for identifying areas of stakeholder divergence and convergence in construction accident-risk perception.

5.4 Significance values for cause-wise stakeholder

Table 7: Significance values for cause-wise stakeholder differences (α = .05)

Cause	Height	Slips	Struck	Electro	Caught	Faulty	Collapse	Fire
Repetitive handling	.013	.005	.005	.089	.030	.001	.007	.053
Heavy lifting	.007	.008	.009	.035	.027	.015	.000	.039
Prolonged single position	.013	.013	.003	.041	.101	.017	.031	.005
Carelessness	.011	.003	.000	.000	.000	.001	.000	.004
Negligence	.005	.000	.000	.000	.000	.001	.001	.007
Structure and design	.011	.003	.004	.010	.006	.008	.013	.014
Project Schedule	.001	.006	.006	.012	.040	.008	.000	.003
Inadequate Budget	.017	.002	.002	.015	.030	.004	.001	.011
Material Quality	.010	.001	.006	.001	.002	.001	.000	.000
Site nature	.002	.006	.016	.004	.012	.018	.031	.027
Climate	.019	.004	.020	.016	.020	.006	.018	.021
Noise	.005	.000	.007	.001	.019	.002	.038	.079
Vibration	.011	.000	.000	.025	.000	.002	.000	.000
Exposure to materials	.007	.003	.018	.003	.001	.000	.058	.000
Long working hours	.001	.001	.004	.006	.002	.000	.019	—
Tight Deadlines	.004	.010	.004	.026	.003	.008	.000	.019
Monotony	.000	.004	.000	.002	.002	.001	.011	.007
Fatigue	.001	.003	.001	.002	.000	.001	.023	.024
Inter-personal relationships	.006	.030	.101	.040	.100	.003	.011	.031
Work assignments	.001	.001	.000	.019	.000	.002	.000	.009
Vendor mis-management	.089	.003	.005	.001	.001	.002	.000	.000
Untrained and incompetent workers	.005	.001	.001	.000	.000	.000	.001	.002
Ineffective supervision and examination	.009	.004	.011	.001	.031	.002	.002	.017

Table 7 presents the p-values associated with the cause-wise stakeholder differences across 23 accident causes and eight accident-risk categories. At the prescribed significance level of α = .05, a p-value below .05 indicates a statistically significant difference among the stakeholder groups, whereas a p-value greater than .05 indicates that the observed difference is not statistically significant. The results provide strong evidence that stakeholder perceptions of construction accident causes vary substantially across most cause–risk combinations.

A striking finding is that Carelessness and Negligence demonstrate statistically significant stakeholder differences across all eight accident categories. For Carelessness, all p-values range from <.001 to .011, while Negligence records p-values from <.001 to .007. This indicates that perceptions of these behavioural causes differ significantly among architects, design engineers, site engineers, site supervisors and construction workers regardless of the accident category. The result highlights the importance of recognising stakeholder-specific interpretations of human and behavioural factors in construction safety management.

The Structure and Design cause also shows statistically significant differences across all eight accident categories, with p-values ranging from .003 to .014. Similarly, Project Schedule, Inadequate Budget and Material Quality demonstrate significant differences for every accident category examined. Particularly noteworthy is Material Quality, where p-values are <.001 for Collapses/Cave-ins and Fire/Explosions, indicating strong stakeholder differentiation in the perception of material-related risks associated with these accident types.

The environmental and physical causes also show predominantly significant differences. Site Nature records significant p-values across all eight accident categories, ranging from .002 to .031, while Climate produces significant differences throughout, with p-values between .004 and .021. Noise is significant for seven of the eight accident categories, with the only non-significant result occurring for Fire/Explosions ($p = .079$). Likewise, Vibration demonstrates significant stakeholder differences across all eight accident categories, with p-values ranging from <.001 to .025.

The results for Exposure to Materials indicate significant differences in seven accident categories. The only non-significant result is for Collapses/Cave-ins ($p = .058$). Long Working Hours is statistically significant for all reported categories, although no p-value is supplied for Fire/Explosions. Tight Deadlines similarly produces significant differences across all eight reported accident categories, with p-values ranging from <.001 to .026.

The work-related causes of Monotony and Fatigue are particularly important. Monotony produces significant differences across all eight accident categories, with p-values ranging from <.001 to .011. Fatigue is likewise significant across all eight categories, with p-values ranging from <.001 to .024. These findings reinforce the importance of work organisation, psychological conditions and human performance in explaining differences in stakeholder perceptions of construction accident risks.

5.5 Areas of stakeholder convergence

Importantly, the results do not indicate universal stakeholder disagreement. Seven cause–risk combinations are explicitly non-significant at $\alpha = .05$:

Table 8: Areas of stakeholder convergence

Cause	Accident risk	p-value	Interpretation
Repetitive handling	Electrocution	0.089	Not significant
Repetitive handling	Fire/Explosions	0.053	Not significant
Prolonged single position	Caught in Between	0.101	Not significant
Noise	Fire/Explosions	0.079	Not significant
Inter-personal relationships	Struck by Objects	0.101	Not significant
Inter-personal relationships	Caught in Between	0.1	Not significant
Vendor miss-management	Falling from Height	0.089	Not significant

These non-significant results are important because they indicate stakeholder convergence in specific cause–risk relationships. For example, the stakeholders do not differ significantly in their perceptions of the relationship between prolonged single position and caught-in-between accidents, or between noise and fire/explosion risks. Therefore, the findings should not be interpreted as evidence that stakeholder perceptions differ for every cause and accident category.

Overall inference

Overall, the overwhelming majority of the 183 reported cause–risk combinations are statistically significant at $\alpha = .05$, demonstrating substantial stakeholder differentiation in the perception of construction accident causes. The strongest consistency is observed for Carelessness, Negligence, Structure and Design, Project Schedule, Inadequate Budget, Material Quality, Site Nature, Climate, Vibration, Monotony and Fatigue, which show significant differences across all their reported accident categories.

Conversely, the limited number of non-significant relationships demonstrates that stakeholder perceptions converge in selected circumstances. This combination of widespread divergence and selective convergence is an important finding of the study.

Accordingly, Table 8 provides stronger evidence than the descriptive RPN profiles alone that construction safety cannot be effectively managed through a uniform stakeholder perspective. The statistically significant differences indicate a need for role-specific safety communication, training, risk assessment and intervention strategies, while the areas of convergence may provide opportunities for establishing common safety priorities across stakeholder groups.

Most importantly, Table 7 and Table 8 should be interpreted together: Table 7 identifies the magnitude and pattern of the reported t-statistics, whereas Table 8 establishes whether the corresponding stakeholder differences are statistically significant. This combined analysis substantially strengthens the statistical contribution of the study by moving from descriptive risk prioritisation to inferential evidence of stakeholder-specific risk perception.

5.6 t-test values by cause domain and accident risk

Table 9: Aggregated t-test values by cause domain and accident risk

Cause domain	Height	Slips	Struck	Electro	Caught	Faulty	Collapse	Fire	Supplied significance
Ergonomic	4.884	7.741	19	13.88	9.003	7.698	6.882	5.286	All significant
Planning	6.675	6.274	13.88	9.798	5.702	8	5.92	6.15	All significant
Physical	13.86	19	9.003	19	5.137	9.003	10.124	13.88	All significant
Person	15.493	8.5	9.69	9.487	9.662	9.003	—	4.226	Reported p-values significant where supplied
Management	10.956	15.493	19	9.662	10.429	19	19	7.98	All significant

Table 9 presents the aggregated t-test values across five major cause domains- Ergonomic, Planning, Physical, Person and Management- and eight construction accident-risk categories. The analysis provides a higher-level interpretation of the cause-wise stakeholder differences reported in Tables 7 and 8 and helps identify whether stakeholder divergence is concentrated within particular causal domains or varies according to the accident mechanism.

The Ergonomic domain records t-values ranging from 4.884 for Falling from Height to 19.000 for Struck by Objects. The highest values are observed for Struck by Objects (19.000) and Electrocution (13.880), while the lowest is for Falling from Height. The supplied significance assessment indicates that all ergonomic-domain comparisons are statistically significant. This demonstrates that stakeholder perceptions associated with ergonomic causes differ significantly across all eight accident-risk categories.

The Planning domain also shows statistically significant differences across all eight accident categories. The t-values range from 5.702 for Caught in Between to 13.880 for Struck by Objects. The highest value occurs for Struck by Objects, followed by Electrocution (9.798) and Faulty Tools (8.000). The result indicates that planning-related factors generate significant stakeholder differences regardless of the particular accident mechanism considered.

The Physical domain exhibits some of the strongest aggregated differences. The highest t-values are 19.000 for Slips, Trips and fall and 19.000 for Electrocution, followed by 13.880 for Falling from Height and Fire/Explosions. The lowest value is 5.137 for Caught in Between. Nevertheless, the supplied significance assessment reports all comparisons as significant, demonstrating that physical and environmental conditions are perceived differently by stakeholder groups across every accident category.

The Person domain records t-values between 4.226 for Fire/Explosions and 15.493 for Falling from Height. The highest stakeholder difference occurs for Falling from Height (15.493), followed by Slips, Trips and fall (8.500), Struck by Objects (9.690), Electrocution (9.487) and Caught in Between (9.662). No aggregated value is supplied for Collapses/Cave-ins, and therefore no inference should be made for that particular combination. The supplied significance information indicates that the reported p-values are significant where available.

The Management domain demonstrates particularly strong stakeholder differentiation for Struck by Objects, Faulty Tools and Collapses/Cave-ins, each recording a t-value of 19.000. Slips, Trips and fall also produce a relatively high value of 15.493, followed by Falling from Height (10.956) and Caught in Between (10.429). The supplied significance assessment indicates that all management-domain comparisons are significant. This finding is particularly important because it demonstrates that management-related causes are not perceived uniformly across the stakeholder groups.

5.7 Comparative interpretation across domains

A comparison of the five domains demonstrates that stakeholder disagreement is not confined to one particular causal category. Instead, the magnitude of differences changes according to the interaction between cause domain and accident mechanism.

Table 10: Comparative interpretation across domains

Cause domain	Highest reported t-value	Accident risk associated with highest value
Ergonomic	19	Struck by Objects
Planning	13.88	Struck by Objects
Physical	19	Slips/Trips/Falls and Electrocution
Person	15.493	Falling from Height
Management	19	Struck by Objects, Faulty Tools and Collapses/Cave-ins

This pattern provides an important finding for the study. Struck by Objects repeatedly appears among the highest aggregated differences, particularly within the Ergonomic, Planning and Management domains. Physical causes demonstrate their strongest differences for Slips/Trips/Falls and Electrocution, whereas the Person domain reaches its highest value for Falling from Height.

Overall inference

Overall, Table 10 demonstrates that stakeholder differences are multidimensional and accident-specific rather than being concentrated within a single causal domain. All reported Ergonomic, Planning, Physical and Management comparisons are identified as significant in the supplied significance column, while the Person domain is reported as significant wherever p-values are available.

The results therefore strengthen the findings of Tables 6 and 7 by demonstrating that the observed stakeholder differences remain evident even after the 23 individual causes are aggregated into broader causal domains. This provides evidence that stakeholder perceptions are influenced not merely by individual causes but by broader dimensions of construction accident causation.

The findings have an important practical implication: a one-size-fits-all safety intervention may not adequately address the different perceptions of architects, designers, site engineers, site supervisors and construction workers. Instead, intervention strategies should be aligned with the specific accident mechanism and the causal domain involved. For example, management interventions may require particular emphasis for struck-by-object, faulty-tool and collapse/cave-in risks, while physical-risk interventions may require greater attention to slips/trips/falls and electrocution.

Thus, Tables 6–8 collectively establish a progressive statistical argument: Table 6 identifies the magnitude of cause-wise stakeholder differences, Table 7 establishes their statistical significance, and Table 8 demonstrates that these differences persist at the broader causal-domain level. This progression substantially strengthens the empirical contribution of the study.

6. Discussion

6.1 Slips, trips and falls as the leading perceived priority

The highest overall RR was recorded for slips, trips and falls. Safety programmes should therefore manage housekeeping, access routes, temporary openings, storage, walking surfaces and work-area organisation as leading safety controls, rather than focusing exclusively on spectacular high-severity hazards.

6.2 Struck-by hazards and operational coordination

Struck-by objects ranked second overall, with the highest stakeholder RR reported by site supervisors. Material movement, lifting activities, equipment and simultaneous

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work require lifting plans, exclusion zones, signalling, traffic management and separation between workers and moving equipment.

6.3 Falling from height remains a high priority

Falling from height ranked third but remained high risk. The result supports continued emphasis on guardrails, safe access, safety nets, fall-arrest systems, inspection of temporary works and competent supervision.

6.4 Management and planning as upstream determinants

The differences observed for planning and management causes demonstrate why safety should extend upstream of the immediate workface. Project scheduling, inadequate budgets, work assignments, worker competence and ineffective supervision can influence several hazard categories simultaneously.

6.5 Stakeholder diversity as a safety resource

Stakeholder disagreement should not automatically be interpreted as a weakness. Workers possess experiential knowledge of recurring site conditions; designers can recognise design-stage hazards; engineers can interpret technical interactions; and supervisors can identify coordination problems. Structured dialogue can convert this diversity into safety intelligence.

7. Theoretical Contributions

- The study integrates ergonomic, planning, physical, person and management domains in one accident-causation framework.
- It incorporates stakeholder risk perception as a formal analytical layer within FMEA-oriented risk assessment.
- It treats construction risk perception as an organisational and role-dependent phenomenon.
- It links descriptive RR, RPN prioritisation and inferential statistical evidence within one decision-support framework.

8. Practical Implications

Table 11: Risk-priority-based safety interventions

Priority	Accident category	Mean RR	Risk level	Recommended controls
1	Slips, Trips and Falls	14.77	Very High	Housekeeping; clear access; slip-resistant surfaces; temporary-opening protection; inspections
2	Struck by Objects	14.23	Very High	Material movement control; lifting plans; exclusion zones; signaling; equipment-worker separation
3	Falling from Height	13.00	High	Guardrails; safety nets; safe access; fall-arrest systems; competent supervision
4	Caught in Between	12.17	High	Machine guarding; exclusion zones; isolation; safe sequencing; supervision
5	Collapses/Cave-ins	9.60	Moderate	Excavation/temporary-works assessment; shoring; competent inspection; monitoring
6	Faulty Tools	7.95	Moderate	Pre-use inspection; maintenance; defective-tool isolation; approved equipment
7	Electrocution	6.23	Low–Moderate	Electrical isolation; testing; protected wiring; competent personnel
8	Fire/Explosions	3.75	Low	Hot-work controls; ignition-source management; safe flammable-material storage; emergency preparedness

For architects and designers, safety should be embedded through design-stage hazard identification and constructability review. Site engineers should translate design and planning requirements into site-specific method statements and permits. Site supervisors should focus on real-time hazard recognition, housekeeping, material movement and coordination. Workers should be involved in toolbox talks, hazard reporting, safety observations and near-miss reporting. Management should allocate resources according to risk priority and ensure high-priority hazards receive stronger engineering, administrative and behavioural controls.

9. Integrated Construction Safety Management Model

The findings support an integrated management cycle:

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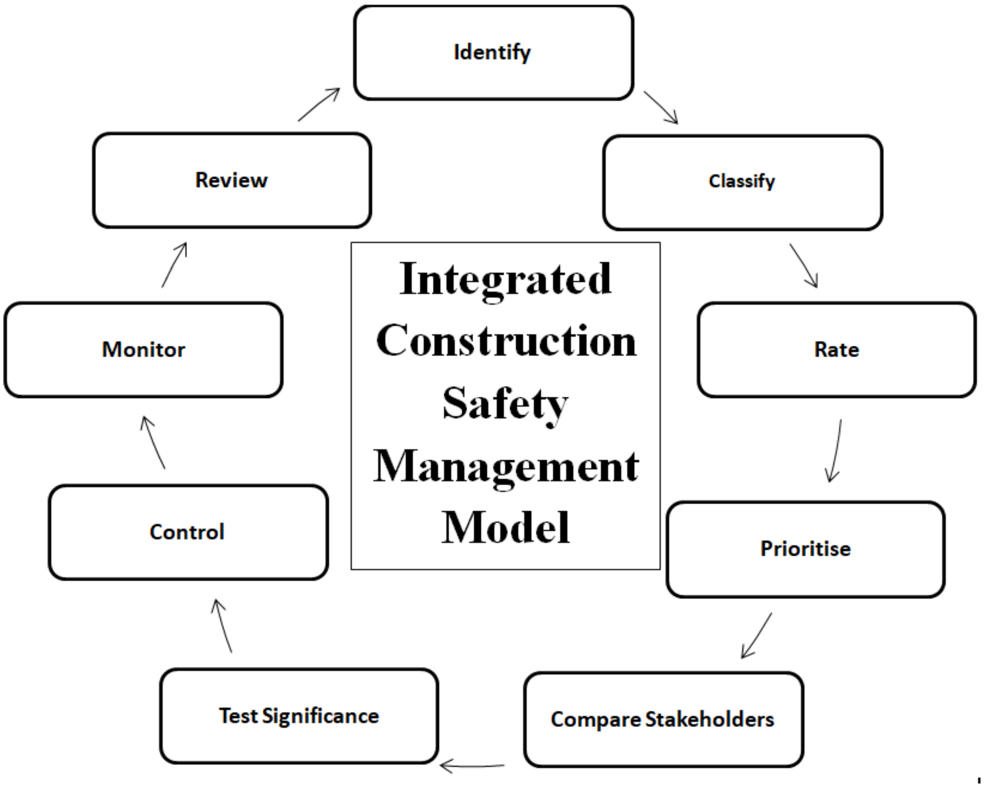

Figure 3: Integrated Construction Safety Management Model
Source: Primary data

The first stage identifies the 23 accident causes. The second classifies them into five domains. The third establishes Risk Ratings. The fourth applies RPN prioritisation. The fifth compares stakeholder perceptions. The sixth identifies statistically significant differences. The seventh develops targeted controls. The final stages – eighth and ninth involve continuous monitoring and review.

This cyclical process is consistent with international occupational safety principles that require risk controls to be reviewed when circumstances change or when accidents, near misses or new information indicate that existing controls are inadequate.

10. Limitations and Future Research

The study relies on stakeholder perceptions rather than longitudinal accident-frequency data; perceived risk should therefore not be equated with actual probability. Conventional RPN also has recognised limitations associated with equal weighting and rank equivalence. The t-tests demonstrate statistical differences but cannot by themselves explain why those differences occur. Finally, the study covers five stakeholder groups and eight accident categories. Future research should validate the framework against longitudinal accident and near-miss records, report complete inferential statistics including degrees of freedom and effect sizes, and apply ANOVA or multivariate methods for multi-group comparison. Fuzzy FMEA, DEMATEL, structural equation modeling and integration with BIM, digital twins, wearable sensing and leading safety indicators offer further research opportunities.

11. Conclusions

This study developed and empirically examined a stakeholder-based framework for moving from construction accident causes to actionable risk priorities. The framework integrates 23 accident causes, five causal domains, eight accident categories, five stakeholder groups, RR, RPN and statistical comparison. Slips, trips and falls emerged as the highest overall perceived risk (14.77), followed by struck by objects (14.23), falling from height (13.00) and caught in between (12.17).

Stakeholder-specific results demonstrate that professional position and exposure influence risk perception. Construction workers gave the highest RR to slips/trips/falls, Site supervisors gave the highest rating to struck-by objects, and Site engineers recorded the highest rating for electrocution. The cause-wise p-values show widespread stakeholder differences but also reveal selected areas of convergence. The principal contribution is therefore an integrated decision pathway: identify causes, classify causal domains, assess risk, compare stakeholder perceptions, test differences, prioritise controls and continuously review performance. Such a system can complement statutory compliance and help Indian construction organisations allocate limited safety resources to the hazards and causal mechanisms that warrant the greatest attention.

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