



DEVELOPMENT OF A RISK-BASED EVALUATION MODEL FOR FIRE SAFETY AND OCCUPATIONAL HAZARDS AT CONSTRUCTION SITES

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Abstract

Construction sites involve complex and continuously changing working conditions that expose workers to fire hazards, occupational injuries, and potentially fatal accidents. Activities such as welding, cutting, electrical installation, material handling, work at height, excavation, and the storage of flammable substances can significantly increase the level of risk. Conventional safety inspections may fail to provide a systematic method for comparing hazards, prioritizing corrective actions, and evaluating the effectiveness of preventive measures. This study proposes a risk-based evaluation model for assessing fire safety and occupational hazards at construction sites. The proposed framework integrates hazard identification, likelihood and severity assessment, risk scoring, hazard prioritization, and the selection of control measures. A five-point risk matrix is used to classify hazards into low, moderate, high, and extreme categories. The model also incorporates fire prevention, emergency preparedness, worker training, housekeeping, electrical safety, and personal protective equipment into an integrated evaluation system. An illustrative assessment demonstrates how the model can be used to prioritize hazardous activities and allocate safety resources. The framework is intended to support construction managers, safety engineers, fire safety professionals, and contractors in improving workplace safety performance. Field validation is required to establish its reliability and effectiveness across different construction environments.

Keywords: Construction safety, fire hazard assessment, occupational risk, risk-based evaluation, hazard identification, fire prevention, risk prioritization, safety management.

1. Introduction

The construction industry is a major contributor to infrastructure development, employment generation, and economic growth. However, construction activities involve numerous occupational hazards because of the simultaneous operation of machinery, temporary electrical installations, elevated work platforms, hot-work activities, combustible materials, and changing site layouts.

Fire hazards are particularly important during construction because permanent fire protection systems may not yet be operational, temporary escape routes may change frequently, and combustible materials can accumulate near ignition sources. Welding, gas cutting, grinding, electrical faults, and improper storage of liquefied petroleum gas cylinders can increase the likelihood of fire incidents.

In addition to fire risks, workers may be exposed to falls from height, falling objects, electrical shocks, excavation collapse, excessive noise, dust, manual-handling injuries, and hazardous chemicals. These hazards can result in injuries, occupational illnesses, project delays, property damage, and financial losses.

The International Labour Organization's revised 2022 *Code of Practice on Safety and Health in Construction* emphasizes systematic hazard prevention, occupational health management, worker participation, training, and effective safety controls. In India, the National Building Code of India 2016 includes provisions relating to fire and life safety and construction management, practices, and safety.

Despite the availability of safety guidance, an effective site-level evaluation process requires a consistent method for identifying hazards, quantifying risks, and determining which hazards require immediate intervention.

Accordingly, this study proposes an integrated risk-based evaluation model that combines fire safety and occupational hazard assessment within a single decision-support framework.

1.1 Research problem

Construction site safety assessments may be affected by inconsistent inspection practices, incomplete incident records, inadequate risk prioritization, and insufficient coordination between fire safety and occupational safety management.

A systematic evaluation model is therefore required to:

1. Identify fire and occupational hazards across different construction activities.
2. Quantify risk using consistent likelihood and severity criteria.
3. Prioritize hazards requiring immediate corrective action.
4. Recommend appropriate preventive and protective measures.
5. Establish measurable indicators for monitoring safety performance.

1.2 Aim and objectives

The primary aim is to develop a risk-based evaluation model for assessing fire safety and occupational hazards at construction sites.

The specific objectives are:

- To identify significant fire and occupational hazards associated with construction operations.
- To develop a numerical risk-scoring method based on likelihood and severity.
- To classify identified hazards according to their risk levels.
- To formulate a hierarchy-based strategy for risk reduction.
- To establish an evaluation framework for monitoring the implementation of safety measures.

2. Review of Literature

Construction safety research emphasizes the importance of systematic hazard identification, preventive controls, worker training, and continuous monitoring.

2.1 Construction occupational safety

The ILO Code of Practice on Safety and Health in Construction provides guidance on workplace safety, machinery, scaffolding, work at height, excavation, electrical hazards, occupational health, and emergency preparedness. It supports a preventive approach throughout the construction project lifecycle.

Occupational hazards are influenced by work sequencing, site conditions, worker competency, equipment maintenance, supervision, and coordination among contractors. Consequently, construction risk assessments should be updated as activities and working conditions change.

2.2 Fire safety at construction sites

Fire risk can arise from the interaction of ignition sources, combustible materials, oxygen availability, and inadequate preventive controls. Typical sources include hot work, temporary electrical systems, fuel storage, gas cylinders, and combustible construction waste.

The National Building Code of India 2016 provides a relevant regulatory and technical reference for fire and life safety and construction safety in India. Its applicability should be considered alongside relevant state and local requirements.

In the United States, OSHA's construction regulations also address fire protection and prevention throughout construction, repair, alteration, and demolition activities.

2.3 Risk-based safety evaluation

A risk matrix provides a structured approach for comparing hazards by combining the likelihood of an incident with the severity of its potential consequences. Such a method can support consistent prioritization, provided that its scoring criteria are clearly defined.

The hierarchy of controls recommends prioritizing elimination, substitution, and engineering controls over administrative controls and personal protective equipment when feasible.

2.4 Research gap

The literature and established guidance provide principles for construction safety and fire prevention. However, practical site management can benefit from a unified evaluation procedure that scores fire hazards and occupational hazards consistently and links each risk score to specific corrective actions.

The present study addresses this practical requirement by proposing an integrated framework. Its contribution is the structured combination of established risk assessment principles rather than a claim that risk matrices or construction safety controls are themselves new.

3. Research Methodology

3.1 Research design

The study adopts a framework-development approach consisting of five stages:

1. Identification of construction activities and associated hazards.
2. Development of likelihood and severity rating scales.
3. Calculation of hazard risk scores.
4. Classification and prioritization of risks.
5. Selection of control measures and establishment of monitoring indicators.

For empirical validation, the proposed model can be applied to building construction sites using structured inspections, worker interviews, safety records, incident reports, and observations of actual work practices.

3.2 Hazard identification

The hazards considered in the proposed model are divided into two principal categories.

A. Fire and life-safety hazards

- Welding, gas cutting, and grinding operations.
- Improper storage of flammable liquids and gases.
- Temporary electrical faults and overloaded circuits.
- Accumulation of combustible materials and waste.
- Inadequate availability or accessibility of firefighting equipment.
- Obstructed emergency exits and escape routes.
- Inadequate hot-work permits, fire watch, and emergency training.

B. Occupational hazards

- Falls from scaffolds, ladders, roofs, and elevated platforms.
- Falling tools, materials, and structural components.
- Electrical shocks and contact with live conductors.
- Excavation collapse and unstable ground.

- Machinery-related injuries and unsafe material handling.
- Exposure to dust, noise, vibration, and hazardous substances.
- Inadequate housekeeping, lighting, access, and personal protective equipment.

Each identified hazard should be documented with its location, associated activity, exposed workers, existing controls, potential consequences, and recommended corrective measures.

3.3 Risk assessment model

The proposed model uses two parameters:

- **Likelihood (L):** The estimated probability or frequency of a hazardous event under the conditions being assessed.
- **Severity (S):** The anticipated seriousness of the consequences if the event occurs.

Both parameters are rated on a five-point scale.

Score	Likelihood	Severity
1	Rare	Negligible injury or damage
2	Unlikely	Minor injury
3	Possible	Injury requiring medical treatment or restricted work
4	Likely	Major injury, serious fire, or substantial damage
5	Almost certain	Potential fatality, multiple casualties, or catastrophic loss

The descriptions should be adapted to the site's incident history, exposure conditions, and organizational risk criteria. For severity, the model uses the credible potential consequence rather than the outcome of the most recent incident.

The initial risk score is calculated as:

$$R = L \times S$$

Where:

- (R) = Risk score
- (L) = Likelihood rating
- (S) = Severity rating

The maximum possible score is 25, while the minimum is 1.

3.4 Risk classification

The proposed model classifies hazards into four categories.

Risk score	Risk category	Required response
1–4	Low	Maintain controls and conduct routine inspections
5–9	Moderate	Implement planned corrective actions and monitor
10–16	High	Apply prompt corrective measures and verify controls
17–25	Extreme	Stop or restrict the affected activity until adequate controls are established

These thresholds are proposed operational criteria for this model, not universal regulatory limits. Site-specific rules may require more stringent action. A credible imminent threat to life requires immediate intervention regardless of the calculated score.

3.5 Integrated risk-based evaluation model

The proposed framework follows the sequence below.

Stage 1: Site inspection. Examine work areas, access routes, temporary electrical systems, hot-work locations, scaffolding, excavations, storage areas, and emergency arrangements.

Stage 2: Hazard recording. Record each hazard and the workers, activities, and assets potentially exposed.

Stage 3: Initial risk scoring. Assign likelihood and severity ratings before additional corrective actions are introduced.

Stage 4: Risk prioritization. Rank hazards according to their calculated scores, considering urgent life-safety concerns separately.

Stage 5: Control selection. Apply elimination, substitution, engineering controls, administrative controls, and PPE in the preferred order, as appropriate.

4. Illustrative Risk Assessment and Analysis

The following table demonstrates the application of the model using hypothetical scores. These examples are not measured findings from an actual construction site.

Hazard	Likelihood (L)	Severity (S)	Risk score	Classification
Hot work near combustible materials	4	5	20	Extreme
Fall from an unprotected edge	4	5	20	Extreme
Temporary electrical fault	3	5	15	High

Improper storage of gas cylinders	3	5	15	High
Falling construction materials	3	4	12	High
Excessive dust exposure	3	3	9	Moderate
Poor housekeeping in access areas	3	2	6	Moderate

The risk scores are calculated using ($R=L \times S$). For example, the hot-work hazard has a likelihood rating of 4 and a severity rating of 5, resulting in a score of 20. Under the proposed classification, it falls within the extreme-risk category.

4.1 Interpretation of the illustrative assessment

The examples demonstrate how the model can distinguish between hazards requiring immediate intervention and hazards that can be addressed through planned improvements.

Hot work near combustible materials requires controls such as removal or protection of combustibles, a suitable hot-work authorization procedure, inspection of the work area, appropriate firefighting equipment, and fire-watch arrangements where required.

Fall hazards require effective edge protection, suitable scaffolds or work platforms, safe access, and appropriate fall-protection systems based on the work and applicable requirements.

Temporary electrical hazards require competent installation and maintenance, protection against contact with live parts, inspection of cables and equipment, and isolation of unsafe systems.

Gas cylinders should be stored, handled, and secured in accordance with applicable requirements, with suitable separation from ignition sources and protection against damage.

Dust exposure and housekeeping issues also require corrective action, even where their numerical scores are lower. A low or moderate score must not be interpreted as permission to tolerate an uncontrolled hazard.

5. Proposed Safety Control Measures

5.1 Fire prevention and protection

The construction project should establish an effective fire prevention programme appropriate to its work activities and stage of development. Principal measures include:

- Implementing hot-work permits and suitable fire-watch arrangements.
- Removing combustible waste and controlling ignition sources.
- Providing appropriate, accessible, inspected firefighting equipment.
- Maintaining safe temporary electrical installations.
- Storing flammable liquids and gases in designated, suitable locations.
- Maintaining accessible escape routes and suitable emergency arrangements.
- Training workers in alarm raising, evacuation, and emergency reporting.

The required measures should reflect applicable fire-safety requirements, the site's fire risk assessment, and the changing availability of permanent fire protection during construction.

5.2 Occupational hazard control

Occupational safety controls should include:

- Guardrails, safe scaffolds, and suitable fall-protection arrangements.
- Inspection and maintenance of machinery, lifting equipment, and electrical systems.
- Safe excavation practices and assessment of ground stability.
- Segregation of pedestrians from moving vehicles and equipment.
- Appropriate dust suppression, ventilation, and exposure controls.
- Safe manual-handling procedures and mechanical lifting aids.
- Suitable PPE selected according to the identified hazards.
- Worker training, toolbox talks, supervision, and incident reporting.

Controls should prioritize eliminating hazards or reducing exposure through engineering measures where feasible, rather than relying exclusively on worker behavior or PPE.

6. Performance Evaluation Indicators

To assess implementation, the model proposes a set of indicators that can be monitored over time.

Indicator	Measurement approach
High-risk hazard closure rate	$\text{High-risk hazards closed and verified} \div \text{high-risk hazards identified} \times 100$
Inspection compliance	$\text{Inspections completed} \div \text{inspections planned} \times 100$
Safety training coverage	$\text{Workers trained} \div \text{workers requiring training} \times 100$
Corrective-action completion	$\text{Actions completed by their deadlines} \div \text{actions due} \times 100$
Emergency drill performance	Evaluation of evacuation, communication, accountability, and identified deficiencies
Incident and near-miss trends	Review of event frequency, severity, and recurring causes

These indicators should be interpreted alongside workforce size, hours worked, construction activity, and changes in reporting practices. An increase in reported near misses may reflect improved reporting rather than deteriorating safety performance.

7. Discussion

The proposed risk-based evaluation model offers a structured way to integrate fire safety and occupational hazard management within a single assessment procedure. By applying consistent scoring criteria, construction managers can identify critical hazards, compare risk priorities, assign corrective actions, and evaluate whether controls reduce exposure.

An important advantage of the model is its adaptability. The same basic procedure can be used for residential buildings, commercial construction, industrial projects, and infrastructure works, provided that hazard registers and scoring criteria are adjusted to the specific activities.

The model can also support digital implementation. A spreadsheet or software-based register could record inspection findings, calculate risk scores automatically, track corrective-action deadlines, and generate risk summaries. More advanced implementations could incorporate incident histories, exposure data, statistical analysis, or predictive algorithms.

Nevertheless, a numerical risk matrix has limitations. Different assessors may assign different likelihood or severity ratings, and multiplying ordinal ratings does not produce a precise probability of loss. The model therefore requires defined rating guidance, assessor training, independent verification for critical hazards, and periodic review.

8. Conclusion

This study proposes a risk-based evaluation model for fire safety and occupational hazards at construction sites. The framework combines hazard identification, likelihood–severity scoring, risk classification, corrective-action prioritization, residual risk assessment, and performance monitoring.

The illustrative application demonstrates how hot-work activities, fall hazards, electrical faults, gas-cylinder storage, falling materials, dust exposure, and housekeeping issues can be assessed using a consistent procedure. The model can help construction organizations focus attention on serious hazards, document corrective actions, and evaluate the effectiveness of safety controls.

Its practical effectiveness will depend on the quality of site inspections, the consistency of risk ratings, worker participation, competent supervision, and verification of control measures. The proposed framework should therefore be field-tested across construction projects before its predictive accuracy or effectiveness in reducing accidents is claimed.

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