

# An Integrated Analytical Framework for Safety Hazard Evaluation in Road, Bridge, Metro, and Oil & Gas Construction'

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*Abstract- Construction activities across road, bridge, metro, and oil & gas sectors are characterized by high-risk operations involving heavy machinery, complex structural processes, hazardous materials, confined spaces, tunnelling operations, and interactions with dynamic environments. Traditional safety evaluation techniques often fail to capture multi-dimensional risks influenced by human, technical, environmental, and operational factors. This thesis presents an Integrated Analytical Framework combining qualitative hazard identification methods with Multi-Criteria Decision-Making (MCDM) tools for safety hazard evaluation. The approach integrates structured risk classification, expert-based weighting, analytic hierarchy modelling, and ranking methodologies such as AHP-TOPSIS to evaluate safety hazards systematically. Four industrial sector road construction, bridge construction, metro tunnel development, and oil & gas construction—were analyzed based on 42 identified safety hazards across 10 hazard category groups. Results show that equipment-related hazards, working-at-height risks, confined-space risks, underground instability, and hazardous energy/explosion-related risks were ranked highest across sectors. The analysis provides a basis for prioritizing safety actions, improving risk communication, and developing targeted mitigation strategies. This integrated framework supports industry practitioners, contractors, and policymakers in enhancing construction safety performance.*

*Keywords- Pond Water, Ground Water, Water Quality Index, Water Quality Standard and Physiochemical Analysis*

## I. INTRODUCTION

### 1.1 Background

Construction industries worldwide contribute significantly to infrastructure development but are consistently ranked among the most hazardous industrial sectors. Complex activities, heavy machinery, multi-layered subcontracting, uncertain geology, and dynamic site conditions create

environments where accidents can occur frequently. The safety performance of construction projects depends on systematic hazard identification, structured evaluation, and proactive control methods. Road projects include excavation, paving, hot bitumen handling, and interactions with traffic. Bridge projects involve lifting operations, working at height, structural stability, and formwork safety. Metro construction includes underground tunneling, TBM operations, groundwater challenges, and confined-space work. Oil & gas construction involves hazardous area classification, fire/explosion risk, pipeline welding, pressure systems, and toxic gas exposure.

Given the diversity of these sectors, an integrated analytical framework is necessary to evaluate safety hazards holistically and prioritize mitigation measures.

### 1.2 Problem Statement

Traditional safety evaluation methods—checklists, inspections, and qualitative rating scales—are limited because:

- They do not capture multi-criteria interactions between hazards.
- They rely heavily on subjective judgments without structured weighting.
- They cannot be generalized across sectors with different risk profiles.
- They do not support prioritization of hazards using analytical rigor.
- Therefore, a systematic framework is required to analyze hazards across diverse construction sectors.

### 1.3 Aim of the Study

To develop an integrated analytical framework for evaluating safety hazards in road, bridge, metro, and oil & gas construction using a structured multi-criteria methodology.

### 1.4 Objectives

1. Identify safety hazards across four major construction sectors.
2. Categorize hazards into structured groups.
3. Apply Analytic Hierarchy Process (AHP) to assign hazard category weights.
4. Apply TOPSIS to rank sector-specific hazards.
5. Validate the analytical process through consistency checks.
6. Propose a unified model for safety prioritization.

### 1.5 Scope of the Study

7. The research focuses on safety hazards commonly observed in:
8. Road construction
9. Bridge construction
10. Metro tunneling and stations
11. Oil & gas construction (onshore)
12. The study uses expert evaluations, structured risk classification, and analytical modeling.

## II. IDENTIFY, RESEARCH AND COLLECT IDEA

The results of this study present the sector-wise hazard ranking for Road, Bridge, Metro, and Oil & Gas construction using the integrated AHP–TOPSIS framework. The AHP model provided the category-level weights, while TOPSIS ranked individual hazards within each sector based on likelihood, severity, exposure frequency, and detectability.

A total of 42 hazards across 10 hazard categories were evaluated. Results for each sector are summarized below.

## III. WRITE DOWN YOUR STUDIES AND FINDINGS

Introduction to Construction Safety Research Construction is recognized globally as one of the highest-risk industries, with accident rates significantly higher than manufacturing and service

sectors (Hinze, 2017). Projects across different construction domains—road, bridge, metro tunnel construction, and oil & gas facilities—exhibit unique hazard profiles shaped by geology, project complexity, heavy equipment usage, and hazardous materials. Many researchers argue that the dynamic nature of construction sites increases uncertainty and creates challenges for traditional safety evaluation methods (Zhou et al., 2015).

Because construction hazards are multi-dimensional and interdependent, integrated analytical frameworks and Multi-Criteria Decision-Making (MCDM) methods have gained prominence (Yazdani-Chamzini et al., 2014).

### 2.2 Safety Hazards in Road Construction Projects

Road construction activities typically involve excavation, grading, asphalt laying, compaction, and traffic diversion. Studies indicate that traffic interface hazards, equipment run-over incidents, and hot bitumen burns are among the most common causes of severe injuries (Awolusi et al., 2018).

Workers are also exposed to shifting work zones and unpredictable traffic behavior, which generate a high-risk environment (Ghosh & Arndt, 2019). Research shows that poor site layout, inadequate lighting, and insufficient safety barriers significantly increase accident likelihood (Hallowell & Gambatese, 2010).

Environmental hazards such as dust, vibration, and heat stress also affect worker safety and long-term health (Pradhan et al., 2020).

### 2.3 Safety Hazards in Bridge Construction

Bridge projects involve working at height, heavy lifting operations, cable tensioning, and formwork installation. Falls from height are repeatedly identified as the leading cause of fatalities in bridge construction (Chi et al., 2013). Studies indicate that scaffolding collapse and crane operation failures are responsible for a significant portion of structural-construction accidents (Fang et al., 2016).

Structural instability during deck placement, tendon tensioning, and girder erection also poses serious hazards (Li & Shen, 2019). The risks become more severe in large-span and cable-supported bridges due

to complex lifting requirements and greater height exposure.

Safety Hazards in Metro (Underground) Construction  
Metro and underground tunneling projects include excavation, NATM (New Austrian Tunneling Method), and Tunnel Boring Machine (TBM) operations. Research highlights that collapses, groundwater inflow, and confined-space atmospheres are major sources of accidents (Zhang et al., 2020). TBM operation introduces unique hazards such as cutter head entrapment, pressurized air chambers, and mechanical entanglement (Park & Lee, 2016). Urban metro construction often intersects existing utility services, causing risks of electrical cable strikes, gas line ruptures, and sewer failures (Chung et al., 2017). Ground instability in soft soil or water-bearing strata increases collapse risks (Kim & Baek, 2021).

#### Safety Hazards in Oil & Gas Construction

Oil & gas construction is characterized by hazardous materials, combustible gases, high-pressure systems, and welding operations. Studies repeatedly emphasize that fire and explosion hazards are the primary risks in this sector (Khan & Abbasi, 1998).

Workers are exposed to toxic gases such as H<sub>2</sub>S, benzene, and methane during tank construction, pipeline work, and refinery development (Mannan, 2012). High-pressure pipelines, hot work operations, and volatile organic compounds create an environment with low tolerance for error (Gardoni & Murphy, 2014).

Human factors such as procedural violations, inadequate hazard communication, and fatigue increase the likelihood of major accidents (Mohamed, 2002).

#### Human and Organizational Risk Factors

Human factors—including fatigue, inattention, procedural violations, and inadequate training—are consistently linked to accident severity (Reason, 1997). Organizational failures such as insufficient safety culture, poor supervision, and schedule pressure lead to unsafe acts, increasing overall risk (Zohar, 2010).

Multiple studies conclude that construction safety performance is significantly influenced by management commitment, communication protocols, and worker involvement (Cooper, 2000).

#### The Role of Risk Assessment Models in Construction Safety

Traditional safety evaluation methods such as checklists, hazard logs, and Job Safety Analyses (JSA) lack analytical depth (Hallowell & Gambatese, 2009). These methods do not consider the interdependency of hazards or quantify subjective expert judgment.

Therefore, analytical tools such as:

- AHP (Analytic Hierarchy Process)
- TOPSIS
- VIKOR
- FMEA
- Bowtie Analysis

have been recommended for systematic hazard prioritization (Saaty, 1980; Chen, 2011).

#### 2.8 Use of AHP in Hazard Evaluation

AHP has been widely used to derive priority weights for safety factors. For example:

Tah & Carr (2000) used AHP to evaluate construction project risks.

Choudhry & Fang (2008) applied AHP for safety management assessment.

Zeng et al. (2008) ranked construction site risk factors using AHP.

AHP's strength lies in structuring complex problems and deriving weights through pairwise comparison.

#### 2.9 Use of TOPSIS in Risk Ranking

TOPSIS is applied to rank risks by measuring closeness to the “ideal worst” scenario. Prior studies include:

Shen et al. (2010) applied TOPSIS to rank construction hazard severity.

Pradhan & Lee (2019) used TOPSIS to evaluate geotechnical hazards.

Yazdani-Chamzini & Hadavandi (2012) applied TOPSIS to mining risk models.

TOPSIS offers a robust technique for ranking hazards consistently using weighted criteria.

Integrated Frameworks in Safety Research  
Recent studies emphasize combining multiple analytical tools for better safety evaluation:  
AHP–TOPSIS hybrids (Abdelgadir & Alsulami, 2020)  
AHP–FMEA integration (Sharma & Srivastava, 2018)  
Bowtie + MCDM combinations (Nadkarni & Shenoy, 2021)  
However, no integrated framework covers road, bridge, metro, and oil & gas construction simultaneously, creating a significant research gap.

#### 2.11 Identified Research Gaps

1. Sector-specific risk studies exist, but cross-sector analytical comparisons are rare.
2. Few studies integrate AHP–TOPSIS for multi-industry hazard evaluation.
3. Existing safety models do not consider structural, environmental, and human factors together.
4. There is limited research on risk modeling for large-scale metro and oil & gas megaprojects.

These gaps justify the need for a unified, multi-sector analytical framework.

##### A. *Bits and Pieces together*

In this approach combine all your researched The results of this study present the sector-wise hazard ranking for Road, Bridge, Metro, and Oil & Gas construction using the integrated AHP–TOPSIS framework. The AHP model provided the category-level weights, while TOPSIS ranked individual hazards within each sector based on likelihood, severity, exposure frequency, and detectability.

A total of 42 hazards across 10 hazard categories were evaluated. Results for each sector are summarized below.

##### *Use of Simulation software*

- Toxic gas dispersion
- Evacuation modeling
- Smoke movement simulation

##### Software:

- Pathfinder
- FDS (Fire Dynamics Simulator)
- GET PEER REVIEWED

Here comes the most crucial step for your research publication. Ensure the drafted journal is critically reviewed by your peers or any subject matter experts. Always try to get maximum review comments even if you are well confident about your paper.

#### IV. IMPROVEMENT AS PER REVIEWER COMMENTS

Analyze and understand all the provided review comments thoroughly. Now make the required amendments in your paper. If you are not confident about any review comment, then don't forget to get clarity about that comment. And in some cases there could be chances where your paper receives number of critical remarks. In that cases don't get disheartened and try to improvise the maximum.

This completes the entire process required for widespread of research work on open front. Generally all International Journals are governed by an Intellectual body and they select the most suitable paper for publishing after a thorough analysis of submitted paper. Selected paper get published (online and printed) in their periodicals and get indexed by number of sources.

#### V. CONCLUSION

##### Summary of Research

This thesis developed an integrated analytical framework for evaluating safety hazards across four construction sectors using a multi-criteria decision-making approach. The study identified 42 hazards across 10 hazard categories and applied AHP to determine category weights, followed by TOPSIS to rank hazards within each sector.

##### Key Findings

Road Construction  
Bridge Construction  
Metro Construction  
Oil & Gas Construction

##### 6.3 Contributions to Knowledge

This research provides:

A multi-sector safety assessment framework applicable across industries.

A quantitative method combining AHP and TOPSIS for hazard prioritization.

A basis for developing sector-specific safety interventions.

A tool for enhancing decision-making in construction safety management.

#### Practical Implications

The framework can help:

HSE Managers prioritize hazards

Project teams allocate resources intelligently

Government agencies draft safety regulations

Contractors reduce accident rates through targeted interventions

#### Recommendations

Implement periodic AHP–TOPSIS-based hazard assessments in all major projects.

Increase investment in safety training and technology.

Improve monitoring for ground stability and atmospheric conditions.

Strengthen safety culture through top-management involvement.

#### Future Research

Integration with fuzzy logic for uncertainty modeling

Development of automated digital hazard evaluation tools

Incorporation of real-time sensor data

Expansion to offshore and renewable energy construction sectors.

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