

Risk Management for Improving Safety in Building Construction

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Abstract

The main aim of this paper is to identify safety risk factors in building construction projects and use of risk management techniques to reduce the impacts of these risk factors. A survey was conducted consist the set of 30 respondents who are working as project managers, engineers and officers in the field of building construction. The responses received were analyzed using Relative Ranking Index (RRI) analysis and various Multi Criteria Decision Making (MCDM) methods. The aim is to explore the main factors that are responsible towards safety risk. Lists of factors in building construction are identified from library resources, literature reviews and 65 major safety risk factors were identified. In risk assessment, a safety questionnaire was designed to assess the top risk factors and to investigate the application of risk management tools. Using RRI method the 65 major factors were prioritized, the top factors having RRI value greater than or equal to 0.75 are considered. Out of 65 major factors 16 factors were above 0.75, these 16 factors were prioritized using Analytical Hierarchy Process (AHP) creating a Hierarchy having 3 levels namely: 1) Goal 2) High level criteria and 3) Low level criteria and ranked accordingly. There were five key risks identified namely: 1) Management processes towards safety 2) Attributes toward safety 3) Fatality at working 4) Individual performance 5) Risk processes.

In this present study, a case-study was presented with utilizing these 16 major safety factors for identifying the maximum risk exposed on the project. This analysis was done by using Multi Criteria Decision making methods which include Analytical Hierarchy processes (AHP), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), Multi Attribute Utility Theory (MAUT).

Keywords: *safety risk, risk management, construction safety, decision making*

1. INTRODUCTION

The construction industry has raised its heights in developing buildings with modern equipments and labor source. Building Construction is very unsafe workplace where most commonly serious and non-fatal vocational injuries occur due to its unique nature. The construction industry has to be given particular in providing Health and safety to the workers, as the construction industry itself is a high risk prone area to get accidents occurred. Although remarkable improvements have been made in safety and health performance in many countries, the construction industry continues to lag behind most of other industries. Building projects are sometimes allied with poor performance and lack of control during the construction phase leading to hurt and fatality making it one of the most dangerous industries. The Aim is to determine the major factors and for measuring risk management in the construction industry to promote safe working environments at building construction sites.

The Occupational Safety and Health Act (1970) is established to provide guidelines for safe worksite practices and to ensure the safety of the workers. The citations that are

issued to the worker by Occupational Safety and Health Administration (OSHA) providing safety. Satish B. Mohan et.al (2002)

R.A. Haslam, S.A.Hide, Gibb, et al. (2004), said that the hierarchy of causal influences, illustrate that accidents occur as a result of the poor interaction between workers or work team, workplace and materials/personal protective equipment that originate due to deficit in the construction design and process, risk management, project management, client and economic influences, or safety training and education. Goran Janačković et.al (2011) described that increasing the effectiveness of OHS increases the safety of an organization as its important. Safety performance indicators measure the changes in the level of safety connected to, response, preparedness and accident prevention over time, which result from the actions taken to reduce appropriate risks.

Chia-Fen Chi et.al (2004) presented the contributing factors that are leading to fatal occupational falls in construction industry. Individual factors included age, gender, experience, and the use of personal protective equipment (PPE). Primary and secondary prevention measures been used to

prevent falls or to mitigate the consequences of falls.

2. AN OVERVIEW OF CONSTRUCTION SAFETY PERFORMANCE IN DEVELOPING COUNTRIES

The construction industry plays a most important in the economy of developing countries and is generally regarded as one of the most essential area in terms of its impact on health and safety (H&S), In the developing countries H&S awareness and performance is low, and has to be improved. Construction in developing countries like India and Pakistan is more labor demanding in the developed areas of the globe, involving 2.5-10 times as many workers per activity. Farooqui (2008). Typically workers tend to be unskilled and migrate in a group, with or without their families, throughout the country in search of employment. But they are usually divided into various fractions. Communication problems related to difference in language, culture and relation tend to inhibit safety on the work site.

Patrick X. W. Zou et.al (2009) described that the main perception of safety risks came from human-and/or procedure related issues, with “low/no safety education”. To lower the construction safety the government should develop collective legislation and safety protection procedures, and enforce

safety education and training to all site participants.

3. SAFETY RISK FACTORS IN BUILDING CONSTRUCTION SITES

The risk factors included in this chapter were obtained from:

A literature review of the factors influencing safety in the construction sites, discussions with safety experts in building construction sites. The characteristics of the construction industry are similar to those of other countries in term of regulations, project types, weather conditions, management systems, labor workforce, etc.

Goran Janackovic et.al (2011) defined the structure of safety factors, performances and indicators into four groups Technical, Human, Organizational and Environmental. Behzad Esmaceli et.al (2015) Quantified safety risks and performed comparative analyses of different safety risks, out of different risks 22 safety risk attributes that lead to struck-by incident were identified and their relative risks were quantified. The attribute-based safety risk data fills a knowledge gap that has long prevented the integration of empirical safety data with technological models.

Lopez-Arquillos et.al (2014) presented an investigation of the activities and related

safety risks in different vertical formwork activities in civil engineering construction. By using the methodology of staticized groups, 12 activities and 10 safety related risks 14 were identified and validated by experts. Every safety risk identified was quantified for each activity.

The literature review was used to identify the risk factors that affect safety in building construction sites. Several risk factors were identified. Similar risk factors were merged together. Few risk factors were deleted, and few new risk factors were added based on the suggestions made by safety experts and professionals in construction industry. Sixty five safety risk factors in building construction were finally selected.

4. RISK MANAGEMENT

The risk management is a structured process which proactively manages the risk events, reduces potential threats, providing proper measures to improve the value for money in construction. To control the level of risk and mitigate its effects, risk management should be applied. The risk management process requires risk identification, analysis and assessment, as the first steps for planning and implementing risk response strategies. P. Jaskowski et.al (2011)

The elements of construction risk management are:

1) identify and classify risk sources, 2) assess risk sources in order to come up with a logical understanding about them, 3) respond to risk sources to give decisions on how to deal with each one of them, and 4) control risk sources throughout the project life cycle.

4.1 Risk Identification

The potential risks are identified by recognizing, filtering, and ranking them in a profile. The risks of different types are placed in different categories by considering their predetermined characteristics.

Martins Claudia Garrido et. al.,(2011) defined Risk identification is an essential step before risk assessment. It is important to consider the different risk sources present in the project and the different risk classifications with a clear distinction between risk sources and effects.

4.2 Risk Assessment

Krantikumar Mhetre et al., (2016) defined the most effective and widely used ones are qualitative and quantitative risk assessments. The choice of the appropriate approach depends on the project type and size, available information, available cost and time, and analyst expertise.

S. M. Renuka et.al (2014) defined a number of systematic models have been proposed for use in the risk evaluation phase of the risk management process. Out Among different approach models AHP model is more effective, because of its systematic approach to structuring risk assessment problems by providing hierarchical approach.

4.3 Risk Response, monitoring and control

Risk response is the establishment of a strategy to mitigate the potential threats and maximize the potential opportunities. Risk monitoring and control is essential to ensure the achievement of the desired effects of the risk response implementation throughout the project life cycle.

Hamzah Abdul Rahman et.al (2013) defined the output of risk monitoring and control will give lessons for future decision makers. The success of the risk response is assessed on an ongoing basis throughout the project to correct any deviation of the implemented strategy and to realign it with the project objectives. It is necessary to loop back to the risk assessment stage, whenever risks change their nature or new risks arise during the project.

5. METHODOLOGY

The risk influencing safety factors Identification were done through literature review and discussions with experienced ones in the building construction field. The literature review was used to identify the risk factors that affect safety in the construction sites. Seventy five risk factors were identified. Some similar risk factors were merged together and few risk factors were deleted, and few new risk factors were added based on the suggestions made by experienced ones in the construction industry. Sixty five safety risk factors were finally selected.

A survey is a pre formulated written set of questions to which respondent record their answers, usually define the type of barrier. This survey was done on total of 30 respondents and the questionnaire forms were distributed among the respondent of survey consists of 2 Project Managers, 3 Assistant Executive Engineers, 16 Site Engineers, 3 Ph.D. Scholars, 4 m.tech students, 2 Safety Engineers. Face to face meetings, phone discussions and email communication were conducted with concerned professionals.

Relative Ranking Index (RRI) is adopted in the selection of criteria using five-point

Likert's scale. Respondents were asked to indicate the level of importance of these barriers on a five-point Likert's scale. 1 means barrier is Unimportant, 2 means of little importance, 3 means Moderately Important, 4 means Important, and 5 means is Very Important. The identified risks in building construction are few sample of potential hazards and can be seen on every building construction site.

5.1 Relative Ranking Index (RRI)

Relative Important Index (RRI) is a technique used for analysis and ranking of safety factors from the feedback given by various respondents. The RRI can be calculated using the following equation

Where, w is the weight assigned by respondent to the factor (ranging from 1 to 5);

X is frequency of each weight age.

A is the highest weight (5 in this study);

N is the Number of respondents in the survey.

The contribution of each of the risk factor to overall in building construction was examined using RRI method and the ranking of the factors in terms of their weights as perceived by the respondents were done.

Table 5.1: Safety factors considered in survey and their Responses from Respondents using RRI method

S/No	Safety Risk Factors	RRI
1	Commitment of management towards contractor safety	0.86
2	Safety Education: orientation and specialized training	0.78
3	Worker involvement at construction site	0.7533
4	Overall accident/incident investigations (workday case)	0.68
5	Safety meetings for supervisors (internal)	0.7
6	Overall drug and alcohol testing	0.66
7	Planning Safety: pre-project and pre-task	0.7333
8	Worker Evaluation	0.6867

9	Staffing for safety on projects	0.7333
10	Management of the risks to the health	0.66
11	Health and welfare, environment of work.	0.6467
12	Adequacy to the innovations of the processes	0.6067
13	Inquiries of accidents and incidents	0.66
14	Implementation of new installations and new equipment	0.68
15	Maintenance of the installations and equipment	0.6667
16	System functioning towards emergency	0.7867
17	Developing safety policies	0.7333
18	Appointing safety responsibilities to safety manager	0.8267
19	Communication between management& workers on site	0.7867
20	Safety Meetings for workers & supervisors (External)	0.7333
21	Safety plans and records	0.72
22	Safety rewards/incentives	0.6733
23	Safety training	0.76
24	Provision of plant and equipment maintenance	0.68
25	Employment of safety officer and safety supervisor	0.84
26	Provision of safe working environment	0.6933
27	Conduction of site safety inspections and supervision	0.74
28	Size of project	0.62
29	Number of subcontractors	0.5467
30	Complexity of project	0.6267
31	Safety knowledge	0.7533
32	Safety Attitude	0.74
33	Investment made towards safety	0.6467
34	Workers' compensation insurance	0.6867
35	Providing First aid box	0.8533
36	Providing medical treatment	0.7533
37	Providing sick ward for injured workers	0.7067
38	Working at heights	0.7867

39	Working with machinery	0.7333
40	Working with noisy machinery	0.68
41	Working near to swinging machinery's	0.6933
42	Working without wearing personal protective equipment	0.8133
43	Working with scaffolding	0.7867
44	Manual handling and lifting operations	0.74
45	Falling into an excavation pit	0.6333
46	Working under high voltage overhead power lines	0.7133
47	Working in confined spaces	0.72
48	Working near to falling objects	0.78
49	Hazards due to electrical Items/works	0.6467
50	Emphasis on tool box meetings	0.7267
51	Conducting safety audits and management reviews	0.7533
52	Individual involvement on worksite	0.8333
53	Maintaining record of previous accidents	0.6733
54	Lack of financial allocation for safety management	0.6933
55	Risk management	0.7867
56	Risk evaluation at stage of construction	0.7333
57	Risk identification, Risk control and Risk control measures to be implemented	0.8
58	Implementing Risk assessment and procedures	0.78
59	Conducting risk assessments before initiating any activity	0.76
60	Compliance with the Risk Factors enlisted in the Code/Manual	0.8267
61	Mock drill for safety due to possible risks	0.7533
62	Compensation for loss if lives	0.7467
63	Hindrance due to language problem	0.6133
64	Lack of co-ordination between workers	0.6867
65	Agreement between Workers & Contractors for Compensation towards major risk.	0.7533

Major safety factors

The top factors having RRI value greater than or equal to 0.75 are considered as Major safety Factors. There are 16 factors considered as main factors when considered

above 0.75, the 16 factors were further prioritized using AHP analysis and were ranked according to their weight age. These major factors are listed in following Table:5.2

Table 5.2: Major factors according to RRI

S/No	Safety Risk Factors	RRI
1	Commitment of management towards contractor safety	0.86
2	Safety Education: orientation and specialized training	0.78
3	System functioning towards emergency	0.78
4	Appointing safety responsibilities to safety manager	0.83
5	Communication between management and workers on site	0.78
6	Safety training	0.76
7	Providing First aid box	0.85
8	Employment of safety officer and safety supervisor	0.84
9	Working at heights	0.78
10	Working without wearing personal protective equipment	0.81
11	Working with scaffolding	0.78
12	Safety knowledge	0.75
13	Individual involvement on worksite	0.83
14	Risk management	0.79
15	Risk identification, Risk control and Risk control measures to be implemented	0.8
16	Compliance with the Risk Factors enlisted in the Code/Manual	0.83

5.1 Analytic hierarchy process (AHP) for prioritizing the major factors

The Analytical Hierarchy Process (AHP) is one of Multi Criteria Decision Methods (MCDM) developed by Saaty in 1970's is a technique to solve complex problem. Thomas L. Saaty (2008).

As seen in the Table 5.2 there were similar RRI values which makes difficult in ranking them. To prioritize these top 16 factors at a time using AHP would be difficult so further

analysis was made creating a hierarchy consisting of Goal, High level criteria and Low level criteria further AHP analysis was done. A structured questionnaire was prepared and survey was carried out using pair wise comparison. The high level of criteria are 1) Attributes toward safety 2) Management processes towards safety 3) Fatality at working 4) Individual performance 5) Risk processes.

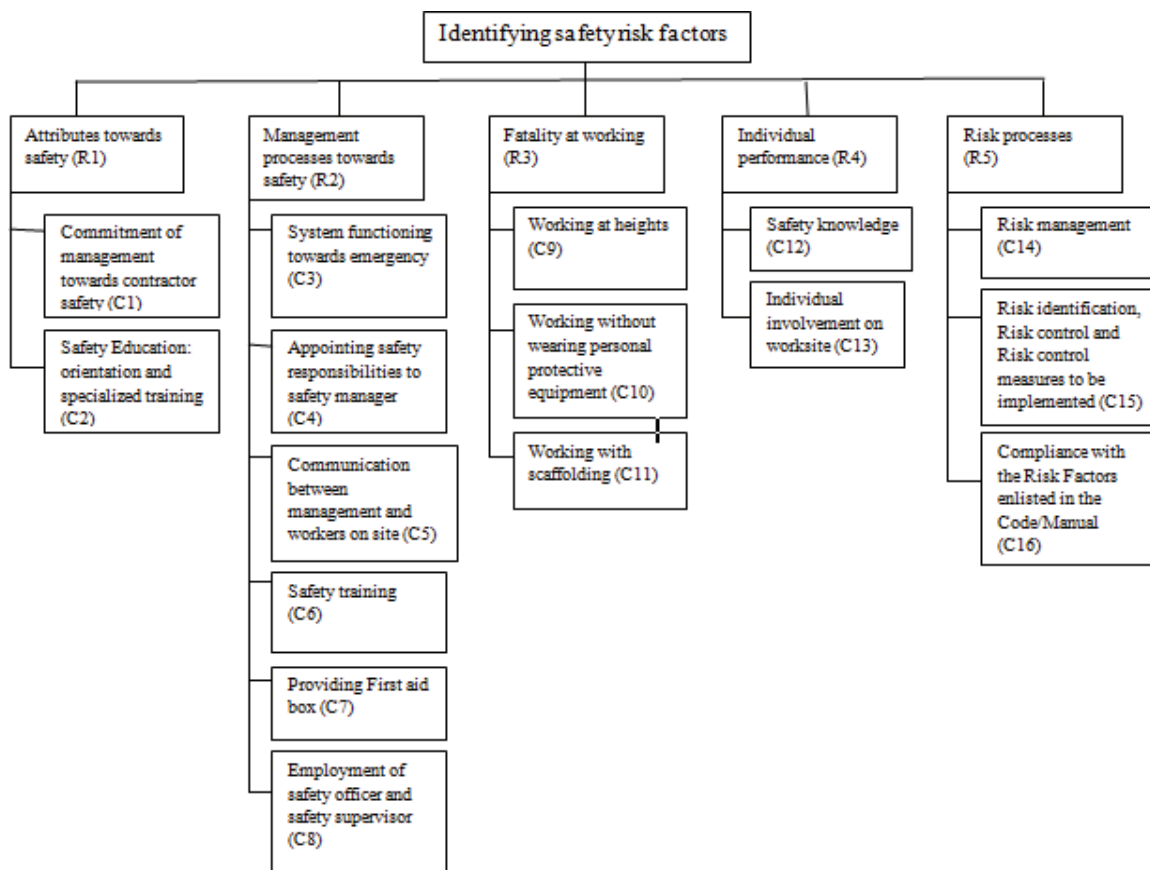


Figure 5.1: Hierarchy showing Goal, high and low level criteria

Table 5.3: Ranking of factors from AHP analysis using weights

High level criteria	Relative Weight	Level 1 Factors	Relative Weight	Aggregation of weights	Priority
F1	0.2695	C1	0.334	0.091	5
		C2	0.667	0.18	1
F2	0.3065	C3	0.331	0.102	3
		C4	0.203	0.063	6
		C5	0.167	0.052	9
		C6	0.142	0.044	10
		C7	0.091	0.028	12
		C8	0.063	0.02	14
F3	0.184	C9	0.527	0.097	4
		C10	0.332	0.062	7
		C11	0.139	0.026	13
F4	0.1761	C12	0.667	0.118	2
		C13	0.334	0.059	8
F5	0.0718	C14	0.541	0.039	11
		C15	0.258	0.019	15
		C16	0.201	0.015	16

Table 5.4: Ranking of factors from AHP analysis

Criteria	Safety Risk Factors
C1	Safety Education: orientation and specialized training
C2	Safety knowledge
C3	System functioning towards emergency
C4	Working at heights
C5	Commitment of management towards contractor safety
C6	Appointing safety responsibilities to safety manager
C7	Working without wearing personal protective equipment
C8	Individual involvement on worksite
C9	Communication between management and workers on site
C10	Safety training
C11	Risk management
C12	Providing First aid box
C13	Working with scaffolding
C14	Employment of safety officer and safety supervisor
C15	Risk identification, Risk control and Risk control measures to be implemented
C16	Compliance with the Risk Factors enlisted in the Code/Manual

6. CASE STUDY

Risk factors Assessment

In this chapter the Risk assessment was made taking the top sixteen criteria as shown in (Table 5.4) and four project Alternatives (Table 6.1) using various multi criteria decision methodologies like Analytic Hierarchy Process (AHP), Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) and Multi Attribute

Utility Theory (MAUT) for both Addition and Multiplication are compared and the features of these models are discussed. The use of MCDM methods in decision making problems provides the response collected and making them converted into weights. The level of risk in these four projects was identified using the four MCDM methods. Below table 6.1 shows the details of the projects taken in the case study:

Table 6.1: Details of four projects taken in the case study

S.No	Details	Project A	Project B	Project C	Project D
1.	Name of work:	Construction of Academic Building (Basement+G+6) For Materials and Metallurgical Engineering Department For National Institute Of Technology (NIT) at Warangal, Telangana, including internal Water Supply. Sanitary installations, Drainage, Electrical In34stallations, Lifts, Firefighting and Fire alarm system.	Construction of Academic Building (Basement+G+6) For Chemical Engineering Department For National Institute Of Technology (NIT) at Warangal, Telangana, including internal Water Supply. Sanitary installations, Drainage, Electrical Installations, Lifts, Firefighting and Fire alarm system.	Construction of Public utility building (Cellar+G+4) For Hospitality at Warangal, Beside Venkatarama Theatre. Including, Electrical Installations, Lifts, Firefighting and Fire alarm system. No. Of rooms 75 No. Of Beds 165	Construction of Dr.B.R.Ambedkar Learning And 450 Nos. Capacity Auditorium With Steel Structure For National Institute of Technology (NIT) Warangal, Telangana.
2.	Name of the Contractor:	M/s Sivanssh infrastructure Development Pvt. Ltd. 002 Gauri Apartments, 57, Hilton Lane, Meera Bai Marg, Lucknow 226 001.	M/s Sivanssh infrastructure Development Pvt. Ltd. 002 Gauri Apartments, 57, Hilton Lane, Meera Bai Marg, Lucknow 226 001.	Hari Babu, AGILE Infrastructure Pvt. Ltd.	Shri. Shaik Akbar
3.	Client:	CPWD	CPWD	Dr. N. Samuel	CPWD
4.	ECPT	Rs.48,11,92,339/-	Rs.49,67,54,383/-	Rs.8,96,00,000/-	Rs.10,73,71,397/-
5.	Time allowed:	600 Days	600 Days	910 Days	450 Days
6.	Date of Commencement:	15/01/2015	15/01/2015	01/05/2014	03/02/2016
7.	Stipulated Date of Completion:	05/09/2016	05/09/2016	01/12/2016	28/04/2017
8.	No. of Workers	260+	300+	60+	60+

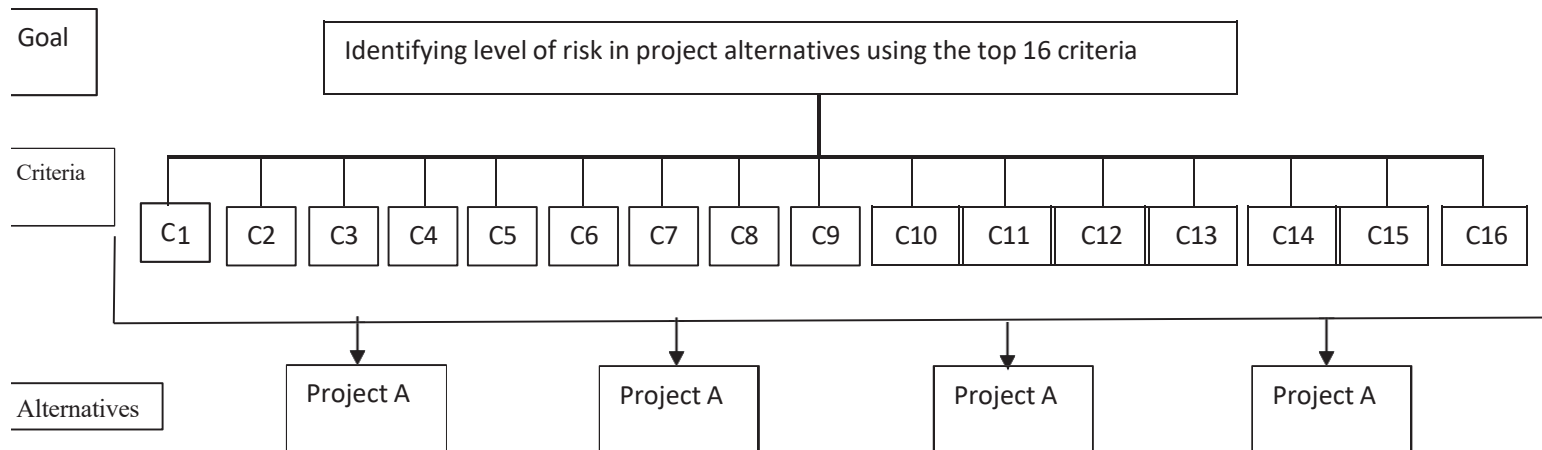


Figure 6.1 Hierarchy showing goal, criteria and alternatives of case study taken

6.1 Analytic hierarchy process (AHP)

AHP is able to assist decision maker in making complex decision. AHP is used in various area such as education, engineering, government, industry, management, manufacturing, personal, political, and social and sports. It is a multi-criteria decision analysis methodology that allows subjective as well as objective factors to be considered in the process which is precisely what is needed.

Steps involved in AHP:

1. Breaking down the decision problem into a hierarchy
2. Comparing the elements in each level in pairs using Saaty's scale, the number of needed

Comparison for (n) criteria is given by $n*(n-1)/2$.

Intensity	Definition
1	Equal importance
3	Moderate importance of one over another
5	Essential or strong importance
7	Demonstrated importance
9	Extreme importance
2,4,6,8	Intensities values between the two adjacent judgments

Table 6.2: Intensities of Relative Importance for Pair wise Comparison

3. Calculating the average relative weight vector.
4. Calculating the relative weights of the alternatives with respect to each criterion.
5. Evaluating the consistency of the resulting weights find the Eigen vectors and the principal Eigen values (λ_{max})
6. Verify consistency index and ratio.

$$CI = (\lambda_{max} - 1) / (n - 1)$$

Inconsistency is calculated using the consistency ratio (CR),

$$CR = CI/RI$$

Where RI is a random number index, the values of which are shown in Table below:

Table 6.3: Random consistency Index

Size of the Matrix	1	2	3	4	5	6	7	8	9	10
Random Consistency	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Table 6.4: overall priorities of alternatives

Criteria	Weight age	Project A	Project B	Project C	Project D
C ₁	0.036	0.9105	0.1738	0.3324	0.1738
C ₂	0.062	0.375	0.125	0.125	0.375
C ₃	0.071	0.0624	0.3151	0.4151	0.2083
C ₄	0.08	0.0576	0.3852	0.3140	0.2442
C ₅	0.062	0.3872	0.0921	0.1353	0.3862
C ₆	0.071	0.1482	0.6264	0.0805	0.1462
C ₇	0.08	0.7091	0.1267	0.094	0.0721
C ₈	0.054	0.375	0.125	0.125	0.375
C ₉	0.027	0.4677	0.2259	0.0801	0.2263
C ₁₀	0.054	0.1609	0.1369	0.3511	0.3511
C ₁₁	0.045	0.5502	0.1971	0.0719	0.1808
C ₁₂	0.071	0.375	0.125	0.125	0.375
C ₁₃	0.08	0.5479	0.3084	0.0911	0.0523
C ₁₄	0.062	0.1463	0.3435	0.3112	0.1990
C ₁₅	0.071	0.2619	0.1240	0.1529	0.4610
C ₁₆	0.08	0.1454	0.4578	0.1640	0.2327
Overall priorities		0.3324	0.2568	0.1864	0.2518
RANK		1	2	4	3

From above table by using total score, Rank of alternative can be determined. Ranking of all alternatives are shown in Table 6.5.

Table 6.5: Ranking of alternatives based on Total score

Project	Relative Closeness	Rank
A	0.3324	1
B	0.2568	2
C	0.1864	4
D	0.2518	3

6.2 Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) Method.

Steps involved in TOPSIS:

1. Construct normalized decision matrix.

Where P_i is the priority of criteria i given by decision maker.

2. Form the decision matrix between alternatives and criteria based on the Decision maker responses.

3. Normalize the decision matrix

$X = (x_{ij})_{m \times n}$ using the equation below

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^m x_{ij}^2}}, i=1,2,\dots,m; j=1,2,\dots,n$$

where r_{ij} is the normalized criterion rating.

4. Calculate the weighted normalized

decision matrix $V = (v_{ij})_{m \times n}$

$$v_{ij} = w_{ij} \cdot r_{ij}, i=1,2,\dots,m, j=1,2,\dots,n,$$

Where w_{ij} is the relative weight of the j^{th}

criterion, and $\sum_{j=1}^n w_j = 1$

5. Determine the ideal and negative-ideal solutions.

$$A^* = v_1^*, v_2^*, \dots, v_m^* = \left\{ \left(\max_j v_{ij} \mid j \in \Omega_b \right), \left(\min_j v_{ij} \mid j \in \Omega_c \right) \right\},$$

$$A^- = v_1^-, v_2^-, \dots, v_m^- = \left\{ \left(\min_j v_{ij} \mid j \in \Omega_b \right), \left(\max_j v_{ij} \mid j \in \Omega_c \right) \right\}$$

Where Ω_b and Ω_c are the sets of benefit criteria and cost criteria, respectively.

6. Calculate the Euclidean distances of each alternative from the positive ideal solution and the negative ideal solution.

$$D_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2}, i=1,2,\dots,m,$$

$$D_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}, i=1,2,\dots,m,$$

7. Calculate the relative closeness of each alternative to the ideal solution. The relative closeness of the alternative A_i with respect to A^* is defined as

$$RC_i = \frac{D_i^-}{D_i^* + D_i^-}; 0 < RC_i \leq 1; i=1,2,\dots,m$$

The larger index value means the better performance of the alternative.

8. Rank the alternatives according to the

Table 6.6: Normalized Decision Matrix

Criteria	Priority (p _i)	Normalized Priority $P = \frac{p_i}{\sum p_i}$
C ₁	4	0.0353982
C ₂	7	0.0619469
C ₃	8	0.0707964
C ₄	9	0.0796461
C ₅	7	0.0619469
C ₆	8	0.0707964
C ₇	9	0.0796461
C ₈	6	0.0530974
C ₉	3	0.0265487
C ₁₀	6	0.0530974
C ₁₁	5	0.0442478
C ₁₂	8	0.0707964
C ₁₃	9	0.0796461
C ₁₄	7	0.0619469
C ₁₅	8	0.0707964
C ₁₆	9	0.0796461

Table 6.7: Decision matrix between alternatives and criteria

Alternatives/criteria	A	B	C	D
C1	5	5	4	4
C2	3	4	3	4
C3	3	3	4	3
C4	4	5	3	4

relative closeness to the ideal solution.

C5	3	2	3	3
C6	4	5	4	3
C7	5	4	2	3
C8	4	3	2	4
C9	5	4	4	3
C10	4	5	3	2
C11	4	5	4	3
C12	2	4	3	4
C13	5	4	5	4
C14	5	5	4	3
C15	2	4	3	4
C16	5	4	2	3

Table 6.8: Normalized Priorities for Criteria

Alternatives /criteria	A	B	C	D
C1	0.553	0.553	0.442	0.442
C2	0.452	0.566	0.452	0.566
C3	0.458	0.458	0.611	0.458
C4	0.493	0.616	0.37	0.493
C5	0.539	0.36	0.539	0.539
C6	0.493	0.616	0.493	0.37
C7	0.681	0.545	0.273	0.409
C8	0.597	0.448	0.299	0.597
C9	0.616	0.493	0.493	0.37
C10	0.545	0.681	0.409	0.273
C11	0.493	0.616	0.493	0.37
C12	0.299	0.597	0.448	0.597
C13	0.553	0.442	0.553	0.442
C14	0.578	0.578	0.462	0.347
C15	0.299	0.597	0.448	0.597
C16	0.681	0.545	0.273	0.409

Table 6.9: Weighted Normalized Decision Matrix

Alternatives /criteria	A	B	C	D
C1	0.0	0.02	0.016	0.016
C2	0.027	0.036	0.027	0.036
C3	0.033	0.033	0.044	0.033
C4	0.04	0.05	0.03	0.04
C5	0.034	0.023	0.034	0.034
C6	0.036	0.044	0.036	0.027
C7	0.055	0.044	0.022	0.033
C8	0.033	0.025	0.017	0.033
C9	0.017	0.014	0.014	0.01
C10	0.03	0.037	0.023	0.015
C11	0.023	0.028	0.023	0.017
C12	0.022	0.043	0.032	0.043
C13	0.045	0.036	0.045	0.036
C14	0.036	0.036	0.029	0.022
C15	0.022	0.043	0.032	0.043
C16	0.055	0.044	0.022	0.033

The Ideal and Negative ideal solutions formed with maximum and minimum values respectively in the columns of normalized weighted decision matrix as follows

$$A^* = \{0.02, 0.27, 0.044, 0.05, 0.34, 0.027, 0.055, 0.033,$$

$$0.017, 0.037, 0.028, 0.043, 0.045, 0.036, 0.043, 0.055\}$$

$$A^- = \{0.016, 0.36, 0.033, 0.03, 0.023, 0.044, 0.022, 0.017,$$

$$0.01, 0.015, 0.017, 0.022, 0.036, 0.022, 0.022, 0.022\}$$

The separation of each alternative from the ideal alternative (D^*) and the anti-alternative (D^-) are determined in terms of Euclidean distances using respectively.

$$D^* = \{0.393065, 0.39598, 0.39598, 0.388844\}$$

$$D^- = \{0.06245, 0.06, 0.036056, 0.047958\}$$

Table 6.10: Ranking of project alternatives

Project	Relative Closeness	Rank
A	0.137098	1
B	0.131585	2
C	0.083455	4
D	0.109794	3

6.3 Validation of Multi-Attribute Utility Theory – Additive Model

A utility function is a device which quantifies the preferences of a decision maker by assigning a numerical index to varying levels of satisfaction of a criterion. All decisions involve choosing one, from several, alternatives. Typically, each alternative is assessed for desirability on a number of scored criteria. What connects the criteria scores with desirability is the utility function. The most common formulation of a multi-criteria utility function is the additive model.

Steps involved in Additive Model:

- 1) Setting the Objective and Establishing the Attributes for the Goal
- 2) Creating Quantitative Figures of the Attributes
- 3) Deriving the Utility Functions of Each Attribute
- 4) Calculating the Weighting Factors of Each Attribute

$$u_j(x_{ij}) = \frac{x_{ij} - x_j^-}{x_j^+ - x_j^-}$$

$$k_j = \frac{w_j}{\sum_{j=1}^n w_j} \quad \text{Where } w_j \text{ is the weight age of } j^{\text{th}} \text{ attribute.}$$

5) Deriving the Multi-Attribute Utility Function each Alternative

$$U_i = k_1 u_1(x_{i1}) + k_2 u_2(x_{i2}) + \dots + k_n u_n(x_{in}) = \sum_{j=1}^n k_j u_j(x_{ij})$$

Table 6.11: Overall Utility Values of projects

Alternatives /criteria	A	B	C	D
C1	0.03	0	0	0.03
C2	0.06	0	0.06	0.03
C3	0.07	0	0	0
C4	0.08	0	0	0.08
C5	0	0	0	0
C6	0.03	0	0	0
C7	0	0	0	0.08
C8	0	0.54	0	0
C9	0.01	0	0.02	0.01
C10	0.05	0.05	0	0.02
C11	0.04	0.04	0.04	0
C12	0	0	0	0.03
C13	0.04	0	0	0
C14	0.06	0	0.06	0.04
C15	0	0	0.07	0.07
C16	0.08	0	0	0
Overall priority	0.57	0.54	0.26	0.41

Table 6.12: Overall Utility Values of projects

Project	Overall Utility	Rank
A	0.137098	1
B	0.131585	2
C	0.083455	4
D	0.109794	3

6.4 Validation of Multi-Attribute Utility Theory – Multiplicative Model

The following are the steps involved in MAUT Multiplicative Model for ranking alternatives.

- 1) Construct pay-off Matrix from Decision Maker's responses
- 2) Calculate range for each attribute
- 3) Ranking of scaling constants of the criteria
- 4) Determination of indifference points
- 5) Derivation of single and multi-attribute utility functions
- 6) Determination of values of scaling constants
- 7) Ascertain the attitude of the decision maker based on overall scaling constant.
- 8) Ranking of the alternatives based on the utility values. Highest utility alternative is best.

Building the Utility Function:

To determine the utility value, there are six steps.

- 1) Identify significant design attributes and generate alternative designs
- 2) Find the range for each attribute and verify relevant attribute conditions
- 3) Use the lottery to determine the user's preference
- 4) Evaluate Single Attribute Utility (SAU) function and trade-off preferences
- 5) Combine SAUs into Multi-Attribute Utility function (MAU)
- 6) Select alternative with the highest MAU value by ranking the alternative.

Multiplicative Equation:

$$U(x) = \frac{1}{K} \left[\prod_{j=1}^n \left(1 + K k_j u_j(x_j) \right) - 1 \right]$$

Where x_j is the performance level of attribute,

$u_j(x_j)$ is the SAU for attribute j ,

k_j is the single attribute scaling constant, and

K is the normalizing constant which scales

$$0 \leq U(x) \leq 1$$

Table 6.13: Utility function of project alternatives

Alternatives/criteria	A	B	C	D
U ₁ (C ₁)	0.983	0.966	1	0.983
U ₂ (C ₂)	0.929	0.994	1	0.989
U ₃ (C ₃)	0.976	0.971	1	0.999
U ₄ (C ₄)	0.963	0.960	1	0.994
U ₅ (C ₅)	0.971	0.980	1	1
U ₆ (C ₆)	0.968	0.969	1	0.994
U ₇ (C ₇)	0.967	0.972	1	0.996
U ₈ (C ₈)	0.978	0.986	1	0.997
U ₉ (C ₉)	0.981	0.971	1	0.999
U ₁₀ (C ₁₀)	0.976	0.993	1	0.991
U ₁₁ (C ₁₁)	1	0.966	0.988	0.995
U ₁₂ (C ₁₂)	1	0.985	0.975	0.987
U ₁₃ (C ₁₃)	0.971	1	0.989	0.983
U ₁₄ (C ₁₄)	0.971	1	0.976	0.997
U ₁₅ (C ₁₅)	0.974	1	0.979	0.996
U ₁₆ (C ₁₆)	0.985	0.98	1	0.998

Table 6.14: Ranking of projects based on Overall Utility

Project	$1+KU(A_i)$	Overall Utility $U(A_i)$	Ranking
A	0.65481	0.50482	1
B	0.72629	0.40028	2
C	0.90824	0.13418	4
D	0.89401	0.15499	3

From the four MCDM methods, it is observed that the Project A was given the first ranking and is exposed to low risk. The results from all the methods are presented

Table 6.15: Ranking of the projects Based on four MCDM methods

Model	Rank for Projects			
	A	B	C	D
AHP	I	II	IV	III
TOPSIS	I	II	IV	III
MAUT Addition	I	II	IV	III
MAUT Multiplication	I	II	IV	III

CONCLUSIONS

The conclusions made from the study are as follows:

1. Sixteen major factors in building construction were identified and prioritized based on RRI analysis and different MCDM methods. The criteria with RRI value > 0.75 are considered.
2. The AHP, TOPSIS, MAUT methods has been introduced and applied in assessing the Importance of safety factors. Risk factors significant to different projects were identified and incorporated in this assessment.
3. The AHP model was developed which consist three layers hierarchy and sixteen major influence factors. The sequence of importance of second level in construction safety influence factor are: 1) Management processes towards safety 2) Attributes toward safety 3) Fatality at working 4) Individual performance 5) Risk processes.
4. The sequence of risk level in case study is identified as Project-C > Project-D > Project-B > Project-A.
5. Conducting similar studies at the organization level is useful to prioritize criteria and sub criteria pull out outcome of safety training programs and to initiate measures to overcome deficiencies.
6. The practice of safety risk management must be enhanced in building construction, further seminars, training and workshops should be carried out in construction companies to address the problems early.

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