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Comparative Study of Risk Indices for Infrastructure Transportation Project Using Different Methods

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Abstract This paper is an attempt to develop and compare the risk indices developed by various methods of project risk analysis like modified expected value method, fuzzy expected value method and fuzzy analytic hierarchy process for an elevated metro rail corridor construction project in Bangalore, India. Risk management is increasingly a critical success factor for major infrastructure projects. It helps to identify, analyse, mitigate and control the risks associated with project cost, schedule and scope. Infrastructure projects are usually faced by different types of risks associated with different types of activities which finally lead to cost and time overrun. The main purpose of this work was to identify the risks and uncertainties associated with major activities of an infrastructure project like elevated metro rail corridor project and then analyse for risk severity and risk index through three different methods. It has been observed that fuzzy expected value method is more sensitive than the other two methods, and the computed values of risk indices predict risk severities which can be ranked according to criticality for almost all the identified activities. Thus, project authorities can easily take necessary mitigation measures to reduce the risk severities. Also, fuzzy expected value method gives good results for both small and large number of activities, whilst modified expected value method works well for up to 25 activities and fuzzy analytic hierarchy process works well for up to 20 activities.

Introduction

Project management issues like cost overrun and time overrun impact a project arising from associated uncertainties and risks. Due to poor risk management, most of the infrastructure projects fail due to huge time and cost overrun. There is relatively very low implementation of formal project risk management methods in practice, leading to the construction industry consistently suffering from poor project performance. This paper is an attempt to develop and compare risk indices through three different risk analysis methods. Askari et al. [1] state that the increasing growth of the construction projects calls for employing effective risk management techniques. The risks involved and associated with the construction of a complex infrastructure project like underground corridor construction for metro rail operations have been studied by Sarkar and Dutta [2]. Their study has enabled in development of a risk management model which would act as a guide for developing risk mitigation strategies for ongoing and future metro rail projects in India. They have developed a questionnaire and personally interviewed the experts from the underground corridor project. In this process, they have identified the risks at various phases of the project starting from the feasibility phase to the completion of the project. Then, they have used the expected value method (EVM) to compute the effect of risky sources in terms of their impact

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and severity. The primary objective of this paper is to study the available methods for risk analysis and then to develop risk indices through application of some of the major risk analysis techniques like modified expected value method (MEVM), fuzzy expected value method (FEVM) and fuzzy analytic hierarchy process (FAHP). The risk indices developed through different methods have been compared, and the relative advantages and disadvantages of each method have been highlighted.

Literature Review

Project risk management is comprised of three basic processes of risk identification, risk assessment and risk response planning. All these processes need to be carried out through all phases of a project starting from feasibility through design, development and implementation. Choi et al. [3] state that risk identification is a process to acknowledge risk events and to identify the characteristics of risk events for the selected project based on the risk-related information. It is of considerable importance because the processes of risk analysis and response strategies may only be performed on the identified potential risks. Kuo and Lu [4] use fuzzy multi-criteria decision-making approach to analyse the risks of metropolitan construction projects. They state that to improve the chance of success and reduce potential risks, in the initial phase, project risks and uncertain factors should be carefully identified, assessed and monitored. Risk index is a measure of the risk severity for activities within a project according to which the necessary mitigation measures can be adopted. Sarkar et al. [5] develop risk indices for quality parameters associated with elevated corridor metro rail project of Delhi using modified analytic hierarchy process (MAHP). Further, Sarkar et al. [6] use fuzzy analytic hierarchy process (FAHP) to develop risk index for elevated corridor metro rail project of Ahmedabad. The risk index developed would act as a guide for deciding risk mitigation measures for future metro rail projects across India.

Saaty [7] explains about analytic hierarchy process (AHP). It is a multi-criteria decision-making (MCDM) management tool for complex situations. The basic approach of AHP is to break down the complex problem into numerous small and simple problems. The main uniqueness of AHP is its inherent capability of weighting a great number of different-natured factors, qualitative and quantitative, in order to make a decision, thereby producing a formal and numeric basis for solution. Mustafa and Al-Bahar [8] explain that the AHP developed by Saaty is a robust and flexible multi-criteria decision analysis methodology. Shapira and Simcha [9] also use AHP methodology for risk analysis. They explain AHP in a simplified manner. Firstly,

the problem is identified and then hierarchy construction is carried out. In this step, list of attributes are generated. The attributes are organized in a hierarchy-type structure that reflects their mutual relationships. The highest level of the structure consists of the primary goal of the problem. The AHP is used for scaling the weight of the risks in each level of hierarchy with respect to risks of the next higher level. The fuzzy AHP model is often used to tackle complex decision-making that calls for subjective judgement on the basis of logical reasoning rather than simple feeling or intuition (Zou et al. [10]). Oliveros and Fayek [11] present useful application of fuzzy logic in solving a construction-related problem like delay and progress of the projects. Li and Zou [12] develop fuzzy AHP-based risk assessment methodology for public–private partnership (PPP) projects and also propose fuzzy AHP for improving the risk assessment accuracy. Rao et al. [13] use fuzzy for selection of optimal contractor for construction industry projects. The final selection is made based on the integrated score in the prequalification and bid evaluation stages. Landfill site selection in Kolkata by the use of AHP as a multi-criteria decision-making tool is carried out by Majumder et al. [14]. Fuzzy-based decision support system is developed by Srinivas et al. [15] for condition assessment and rating of bridges. Roy et al. [16] use fuzzy logic for preventive maintenance of hydropower plants so that power generation is not interrupted. Further, Eom and Paek [17] develop an environmental risk index model for general contractors to minimize third-party environmental disputes at construction sites. Also, interpretive ranking process (IRP) model is developed by Mhatre et al. [18] for critical risk factors of Indian construction industry projects.

Reviewing the available literature, it is observed that various authors have used AHP, fuzzy, EVM and fuzzy AHP methods for risk analysis of projects. But fuzzy EVM and modified EVM were not used by any of the researchers and field experts. The present research aims at developing risk index using MEVM, FEVM and FAHP for a multi-disciplinary complex infrastructure project like construction of elevated corridor for metro rail operations in Bangalore, India. This would help the project authorities in prioritizing and ranking the major identified risks and thus in adopting suitable risk mitigation measures in reducing the severities of the identified risks.

Conceptual Framework

Risk Index Calculation by Modified Expected Value Method (MEVM)

Sarkar and Dutta [2] have used EVM for underground metro project. They considered critical path method (CPM)

network, which has "N" activities represented by $n = (1, \ldots, N)$, and "M" risk sources indicated by $m = (1, \ldots, M)$. They had extended the work of Nicholas [19].

The weightage of each activity is computed from the feedback by 61 experts received through the questionnaire survey:

$$\sum_{m=1}^{M} W_{mn} = 1 \quad \text{for all} \quad n(n = 1, \ldots, N). \tag{1}$$

The likelihood of all risk sources for each activity n can be combined and expressed as a single composite likelihood factor. The weightages of the risk sources of the activities are multiplied with their respective likelihoods to obtain the CLF for the activity. The relationship of computing the CLF as a weighted average is given below:

$$(\text{CLF})_n = \sum_{m=1}^{M} L_{mn} \cdot W_{mn} \quad \text{for all} \quad n \tag{2}$$

$$(\text{CIF})_n = \sum_{m=1}^{M} I_{mn} \cdot W_{mn} \quad \text{for all} \quad n \tag{3}$$

$$0 \leq I_{mn} \leq 1 \sum_{m=1}^{M} W_{mn} \quad \text{for all} \quad n$$

where L_{mn} is the likelihood of mth risk source for nth activity, W_{mn} weightage of mth risk source for nth activity, I_{mn} impact of mth risk source for nth activity, CLF_n composite likelihood factor for nth activity, CIF_n composite impact factor for nth activity.

Further, CIF and CLF were calculated for each attribute using Eqs. (2) and (3), respectively. The severity risk value for each major activity was computed by product of CIF and CLF using Eq. 4:

Risk severity$_{(1,\ldots,N)}$ by EVM $= \text{CLF}_n \times \text{CIF}_n$. \hfill (4)

The risk severity was computed for each attribute using Eq. 4. Finally, risk index (RI) for every major activity was computed by product of risk severity and normalized weight of that particular activity using Eq. 5

$$\text{Risk index}_{(1,\ldots,N)} \text{ by MEVM} = (\text{risk severity})_n$$
$$\times (\text{normalized weight})_n \tag{5}$$

where "N" activities and are represented by $n = (1, \ldots, N)$.

Risk Index Calculation by Fuzzy Expected Value Method (FEVM)

To convert each linguistic variable into fuzzy values, there was a need to define five membership functions for risk severity. The membership functions are defined with

triangular fuzzy numbers. The computation with triangular fuzzy is relatively simple in comparison with trapezoidal fuzzy. The membership functions were defined with values "very low", "low", "medium", "high" and "very high" according to their likelihood and their impact of risk. The values of the linguistic scale were chosen from 0 to 5 at an increment of 1. The values of likelihood and their impact of risk range from 0 to 5 (refer Fig. 2).

The CLF and CIF values acquired from EVM method for all 24 major activity risks were used as inputs for fuzzy method by using MATLAB software to find out the risk severity by fuzzy EVM method. After the calculation of risk severity by incorporating fuzzy in EVM, RI can be computed by multiplying normalized weight with fuzzy risk severity.

Figure 1 highlights the triangular fuzzy membership function where the variable "l" indicates the extreme left value, "m" is the middle value and "n" is the extreme right value.

Figure 2 represents the triangular membership function with the linguistic scale both quantitative and qualitative. The detailed equation for fuzzy membership function is presented in Eq. (6):

$$\text{triangle}\,(x; l, m, n) = \begin{cases} 0, & x \leq l \\ \dfrac{x - l}{m - l}, & l \leq x \leq m \\ \dfrac{n - x}{n - m}, & m \leq x \leq n \\ 0, & n \leq x \end{cases} \tag{6}$$

where x is the mean of probability (P)/impact (I)/detection (D) plotted on x axis, l leftmost value in a triangle, m middlemost value in a triangle, n rightmost value in a triangle.

Figure 3 highlights the MATLAB representation for the triangular membership function for likelihood parameter in which the membership functions were defined from "very low" to "very high" with linguistic scale chosen from 0 to 1 at an increment of 0.25.

Further, the risk index through FEVM can be computed through the following equation:

$$\text{Risk index}_{(1,\ldots,N)} = (\text{risk severity by FEVM})_n$$
$$\times (\text{normalized weight})_n \tag{7}$$

where "N" activities are represented by $n = (1, \ldots, N)$.

Risk Index Calculation by Fuzzy Analytic Hierarchy Process (FAHP)

Saaty [7] had explained about analytic hierarchy process (AHP). Shapira and Simcha [9] had explained AHP methodology in greater detail. The number of attributes, which are the major risks associated with the project, need
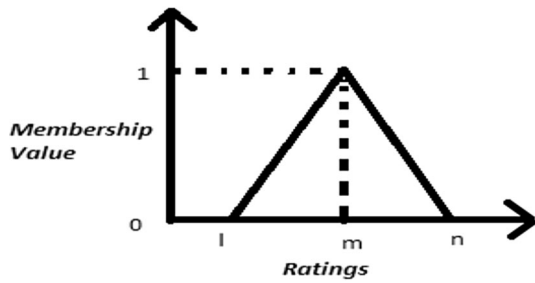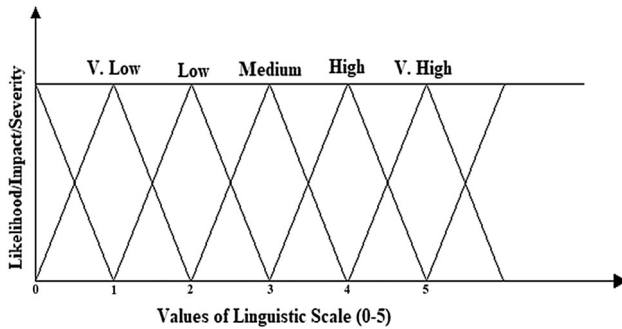
Fig. 1 Triangular membership function

Fig. 2 Membership function with linguistic scale

to be identified. The second step is pairwise comparison. Importance of two attributes is compared by giving them numbers on a Satty scale (1, 3, 5, 7, 9). The third step is the formulation of synthesized matrix. This matrix is obtained from the pairwise comparison matrix. Each element of the synthesized matrix is obtained by dividing the value of the element of the pairwise comparison matrix by their respective column total. The outcome of synthesized matrix is priority vectors (PVs). These are obtained by the addition of the elements in each row of the synthesized matrix and then dividing by the number of the elements in that row. The highest value of the vector is given the maximum priority.

Relative Weight Computation

Several iterations are used to compute the eigenvector, of the comparison matrix, of which the average of normalized columns (ANC) method is the most accurate. ANC computation of vector Wx for the relative weight of the attribute in row i which is an element of the eigenvector W, for a reciprocal $N \times N$ matrix, is as follows:

$$Wx = \frac{1}{N} \sum_{y=1}^{N} \left(Axy / \sum_{l=1}^{N} Aly \right) \qquad (8)$$

where n is the number of rows or columns in a square matrix, Wx the relative weight of the attribute in row x, Axy

Fig. 3 MATLAB representation for membership function "likelihood ranges"
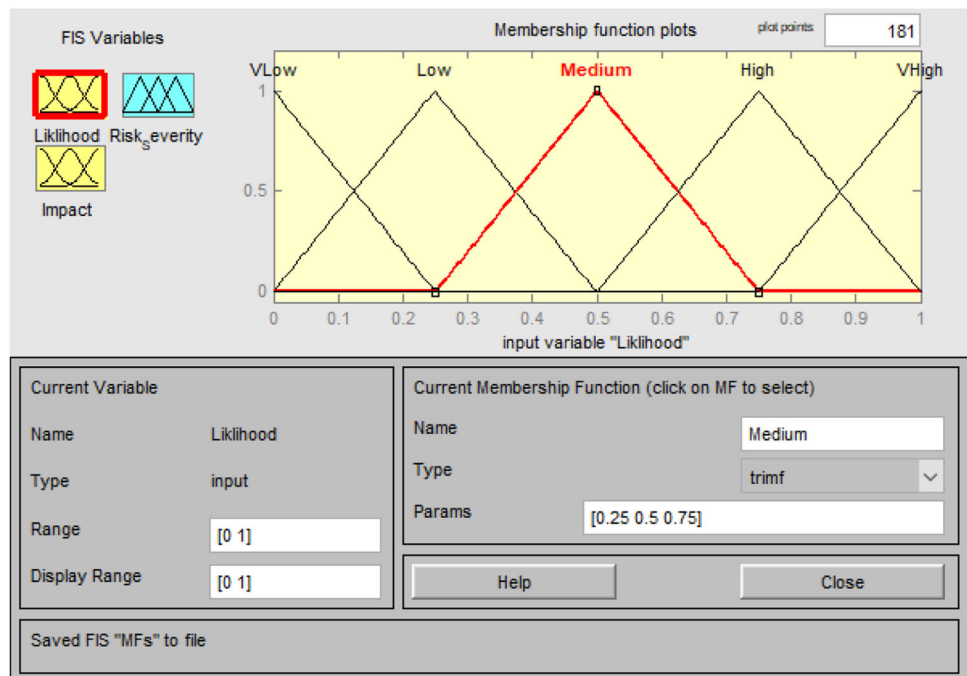
Table 1 Final risk severity values, risk index and ranks by MEVM

S. no. [1]	Description of project risk (activity) [2]	CLF [3]	CIF [4]	Quantitative final risk severity ([3] × [4]) [5]	Qualitative final risk severity [6]	Normalized weight [7]	Final risk index ([5] × [7]) [8]	Ranking [9]
1	Feasibility and DPR risks	0.430	0.857	0.368	Very high risk	0.05	0.01832	4
2	Risks in tender and award of contract	0.402	0.818	0.329	High risk	0.04	0.01464	11
3	Risks in land handover	0.541	0.866	0.468	Very high risk	0.06	0.02963	3
4	Risks in drawing receipt	0.441	0.773	0.341	High risk	0.05	0.01573	9
5	Risks in topographical survey works	0.287	0.804	0.231	Medium risk	0.03	0.00722	22
6	Risks in traffic and utility diversion	0.570	0.876	0.499	Very high risk	0.07	0.03369	2
7	Risks in shuttering works	0.207	0.798	0.165	Medium risk	0.02	0.00368	24
8	Risks in casting yard set-up	0.335	0.793	0.266	Medium risk	0.04	0.00957	17
9	Risks in road widening and barricading work	0.374	0.764	0.286	Medium risk	0.04	0.01107	16
10	Risks in casting of test piles	0.451	0.737	0.332	High risk	0.04	0.01491	10
11	Risks in segment casting	0.454	0.800	0.363	Very high risk	0.05	0.01783	5
12	Risks in piling works	0.406	0.776	0.315	High risk	0.04	0.01343	14
13	Risks in launching girder installation and segment erection	0.606	0.845	0.512	Very high risk	0.07	0.03547	1
14	Risks in pier works	0.409	0.800	0.327	High risk	0.04	0.01345	13
15	Risks in pre-stressing	0.441	0.795	0.350	Very high risk	0.06	0.01760	7
16	Risks in post-tensioning	0.445	0.801	0.353	Very high risk	0.05	0.01773	6
17	Risks in construction planning	0.362	0.859	0.311	High risk	0.04	0.01309	15
18	Risks in obligatory span	0.455	0.721	0.328	High risk	0.04	0.01456	12
19	Risks in span alignment works	0.313	0.742	0.232	Medium risk	0.03	0.00728	21
20	Risks in bearing works	0.325	0.753	0.245	Medium risk	0.04	0.00730	20
21	Risks in parapet casting	0.236	0.812	0.192	Medium risk	0.03	0.00499	23
22	Risks in parapet erection	0.445	0.780	0.348	High risk	0.05	0.01639	8
23	Risks in cable tray	0.312	0.767	0.239	Medium risk	0.03	0.00773	19
24	Risks in expansion joint	0.348	0.708	0.246	Medium risk	0.03	0.00819	18

element located in row x and column y of the comparison matrix, Aly element located in row k of any normalized column $x, y, l = 1, 2, …, N$.

Weighted Sum Matrix

The weighted factor elements of the weighted sum matrix are obtained by multiplying each element of the pairwise comparison matrix by their respective priority vector. The weighted sum is the summation of the elements row-wise. The eigenvalues (λ) are obtained from the following relationship:

$$\text{Eigen value} = \text{weighted sum} / \text{PV} \qquad (9)$$

$$\text{Priority vectors} = \sum_{n=1}^{N} \frac{\text{synthesized matrix}}{N} \qquad (10)$$

$$\lambda\text{max} = \sum_{n=1}^{N} \frac{\lambda}{N} \qquad (11)$$

$$\text{Consistency index} = (\lambda\text{max} - N)/(N - 1) \qquad (12)$$

where n is the number of attributes.

The consistency ratio (CR) is a measure for controlling the consistency of pairwise comparisons. Consistency ratio (CR) is to measure how consistent the judgements have been relative to large samples of purely random judgements. Value of consistency ratio should be less than 0.2 for more consistent judgements

$$\text{Consistency ratio} = \text{Consistency index/Random consistency index} \qquad (13)$$

where RC is the random consistency index

$$(\text{PV for EV})n = \frac{\text{EV}n}{\sum_{n=1}^{N} \text{EV}n} \qquad (14)$$

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Table 2 Final risk severity values, risk index and ranks by FEVM

S. no.	Description of project risk (activity)	Final risk severity		Normalized weight	Final risk index ([3] × [5])	Ranking
		Quantitative	Qualitative			
[1]	[2]	[3]	[4]	[5]	[6]	[7]
1	Feasibility and DPR risks	0.688	Very high risk	0.04	0.03087	7
2	Risks in tender and award of contract	0.672	High risk	0.04	0.02945	9
3	Risks in land handover	0.777	Very high risk	0.05	0.03937	2
4	Risks in drawing receipt	0.682	High risk	0.04	0.03033	8
5	Risks in topographical survey works	0.569	Medium risk	0.04	0.02111	18
6	Risks in traffic and utility diversion	0.781	Very high risk	0.05	0.03978	1
7	Risks in shuttering works	0.560	Medium risk	0.04	0.02045	20
8	Risks in casting yard set-up	0.599	High risk	0.04	0.02340	16
9	Risks in road widening and barricading work	0.624	High risk	0.04	0.02539	15
10	Risks in casting of test piles	0.664	High risk	0.04	0.02875	10
11	Risks in segment casting	0.700	Very high risk	0.05	0.03195	5
12	Risks in piling works	0.650	High risk	0.04	0.02755	11
13	Risks in launching girder installation and segment erection	0.769	Very high risk	0.05	0.03856	3
	…					
	…					
	…					
24	Risks in expansion joint	0.548	Medium risk	0.04	0.01958	21

where $n = (1, …, \text{to } N)$.

The responses obtained from the questionnaire survey responded by about 61 experts were in a risk rating scale of 0–1, where "0" indicates low-risk situation and "1" indicates very-high-risk situation causing huge time and cost overrun of the project. For computational simplicity, we have converted risk rating values obtained from questionnaire survey into "Satty scale" (1, 3, 5, 7, 9) with the help of which pairwise comparison matrix was constructed both for likelihood and for impact reviews. Then, synthesized matrix is constructed for both likelihood and impact reviews. The outcomes of synthesized matrix were priority vectors. These were obtained by summing up the elements in each row of the synthesized matrix and then dividing by the number of the elements in that row.

Methodology

The methodology adopted for this research is primary data research where primary data have been collected from Bangalore Metro Rail Corporation (BMRC). The risks associated and involved in the construction of the elevated corridor metro rail were identified by the personal experience of the authors and by interaction with experts and professionals associated with the construction of the metro rail projects across India. Twenty-four major risks were identified, and a questionnaire was prepared. The respondents need to respond about the likelihood, impact and weightage associated with each risk factor. A sample questionnaire is presented in "Appendix 1" section. The questionnaire was circulated to 85 experts and professionals, out of whom 61 experts and professionals responded to this study. The experts and professionals were project managers, deputy general managers, project engineers, site engineers, quality control engineers, safety engineers, supervisors, foreman and construction equipment operators. The inconsistent responses were modified by carrying out a second round of questionnaire survey through Delphi method. Finally, the responses obtained from 61 experts were analysed through MEVM, FEVM and FAHP to obtain the risk severity and risk index.

Case Study

The case study undertaken for this research work is Bangalore elevated metro rail project. The construction is being executed by IL and FS Company Limited starting from the Nayandahalli to RV college station. The length of

Table 3 Final risk severity values, risk index and ranks by FAHP

S. no.	Description of project risk (activity)	Final risk severity		Normalized weight	Final risk index ([3] × [5])	Ranking
		Quantitative	Qualitative			
[1]	[2]	[3]	[4]	[5]	[6]	[7]
1	Feasibility and DPR risks	0.162	Very high risk	0.05	0.00742	1
2	Risks in tender and award of contract	0.161	Very high risk	0.05	0.00732	2
3	Risks in land handover	0.159	Very high risk	0.04	0.00715	3
4	Risks in drawing receipt	0.147	Very high risk	0.04	0.00611	6
5	Risks in topographical survey works	0.142	High risk	0.04	0.00570	11
6	Risks in traffic and utility diversion	0.152	Very high risk	0.04	0.00654	4
7	Risks in shuttering works	0.150	Very high risk	0.04	0.00636	5
8	Risks in casting yard set-up	0.140	Medium risk	0.04	0.00554	13
9	Risks in road widening and barricading work	0.146	Very high risk	0.04	0.00603	7
10	Risks in casting of test piles	0.142	High risk	0.04	0.00570	11
11	Risks in segment casting	0.147	Very high risk	0.04	0.00611	6
12	Risks in piling works	0.144	High risk	0.04	0.00578	10
13	Risks in launching girder installation and segment erection	0.152	Very high risk	0.04	0.00654	4
	…					
	…					
	…					
24	Risks in expansion joint	0.144	High risk	0.04	0.00587	9

the section under study is 4.2 km. There are four elevated stations. A total of 133 piers and 540 piles would be constructed. The weight of each segment is 14 tons. For this section, IL and FS Company Limited will produce, erect and launch 1180 segments for the viaduct from Nayandahalli to RV college station. The methodology of research work was the formulation of questionnaire. Firstly to identify the major activities and risks involved from the beginning to handing over of the project, the responses of 61 experts associated with metro rail corridor projects were used as inputs for computation of the risk severity. Two rounds of discussions were carried out with metro officials and staff including construction equipment operators, foreman, supervisors, site engineers, project engineers, site in charges, project managers, deputy general managers, quality control engineers and safety engineers. Discussion with consultants and chief engineer was also carried out for the finalization of questionnaire, rating scales and their responses. The risk assessment is carried out in terms of risk severity index and their ranks.

Analysis and Results

For the elevated corridor metro rail construction project, the risk severity of each major activity of the project is computed for all 24 major activities which are presented in

Table 1. After the calculation of risk severity by EVM method, risk index was calculated by multiplying risk severity with normalized weights (Table 1).

Table 1 represents the final risk severity values (both qualitative and quantitative), final risk index values and ranks through MEVM of all the 24 activities involved in the construction of the elevated corridor metro rail construction project. The scale for risk severity is "0.000–0.100 (very low risk)", "0.101–0.149 (low risk)", "0.150–0.299 (medium risk)", "0.300–0.350 (high risk)" and "0.351–1.000 (very high risk)". It has been observed that through MEVM activity risks like "risks in launching girder installation and segment erection", "risks in traffic and utility diversion", "risks in land handover", "feasibility and DPR risks" and "risks in segment casting" have obtained first to fifth rank, respectively, based on the risk index values. These activities need to be monitored with utmost care by the project authorities. The risk index scale ranges from 0 (very low risk) and 1 (critical risk). Risk index scale along with the classification is presented in "Appendix 2" section.

Table 2 represents the final risk severity values, final risk index and ranks computed through FEVM of 14 activities amongst the 24 activities involved in the construction of the elevated corridor metro rail project. The CLF and CIF values obtained from EVM method for all 24 major activities were used as inputs for fuzzy method by

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Fig. 4 MATLAB representation for risk severity for activity "risks in piling works" (FAHP)
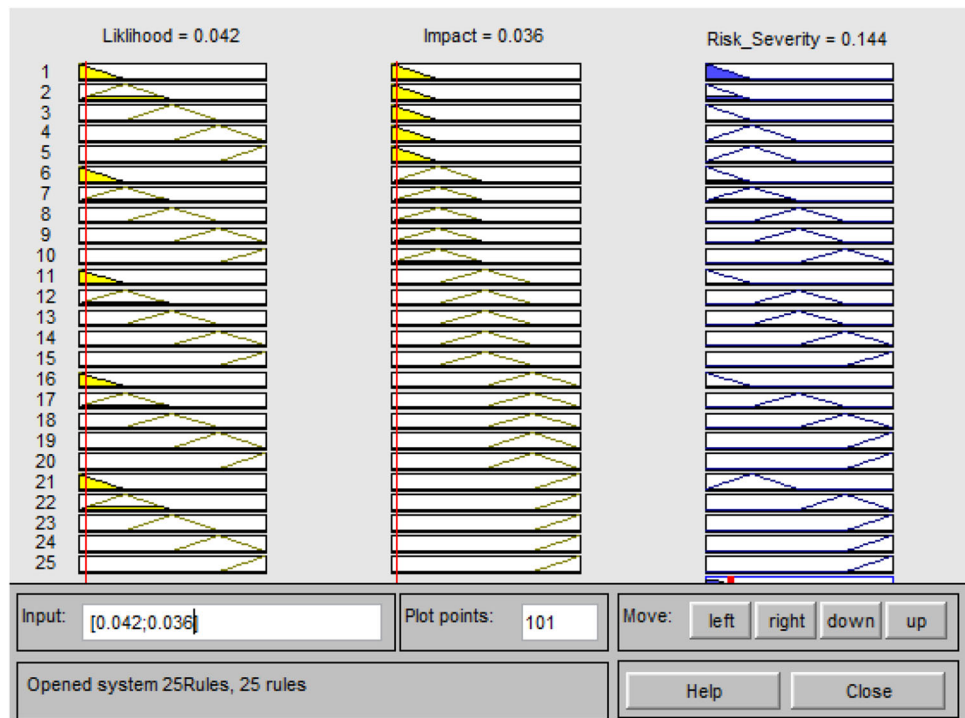
using MATLAB software (Mathworks.Matlab.R2010a). Five membership functions and 25 rules were created in software. The outputs are obtained for all 24 activities considered for this study. The scale for risk severity is "0.000–0.100 (very low risk)", "0.101–0.299 (low risk)", "0.300–0.569 (medium risk)", "0.570–0.684 (high risk)" and "0.685–1.000 (very high risk)". Through FEVM, activity risks like "risks in traffic and utility diversion", "risks in land handover", "risks in launching girder installation and segment erection" and "risks in segment casting" have obtained first to fifth ranks according to risk index values.

The risk severity, risk index and risk ranking obtained through FAHP for 14 activities amongst the 24 activities are presented in Table 3. The scale for risk severity is "0.000–0.100 (very low risk)", "0.101–0.130 (low risk)", "0.131–0.140 (medium risk)", "0.141–0.145 (high risk)" and "0.146–1.000 (very high risk)". It has been observed that through analysis by FAHP activity risks like "feasibility and DPR risks", "risks in tender and award of contract", "risks in land handover", "risks in traffic and utility diversion" and "risks in shuttering works" have obtained first to fifth rank, respectively, according to the risk index values. The MATLAB representation for the activity "risks in piling work (A12)" for computation of risk severity is presented in Fig. 4.

The final risk indices computed through MEVM, FEVM and FAHP for all the 24 activity risks for the construction

of the elevated corridor metro rail project are presented in Table 4. The comparison of the graphical representation of risk indices by all the three methods is presented in Fig. 5.

From Table 5 and Fig. 5, it has been analysed that FAHP method is having very narrow risk severity range (0.140–0.162) and very narrow risk index range (0.0055–0.0074). Also, there is overlap of rankings and only 13 ranks for 24 activity risks can be obtained. The risk index curve of FAHP has minimum fluctuations. The risk index curve obtained through MEVM has higher fluctuations than FAHP. Further, MEVM method is having good risk severity range (0.165–0.512) and good risk index range (0.00368–0.03547). Also, 22 ranks are obtained for 24 activities. The risk index curve for FEVM method is more fluctuating than FAHP and MEVM. Further, FEVM has the widest risk severity range (0.501–0.781) and widest risk index range (0.01637–0.03978). There is only one overlap of rankings, and 23 ranks are obtained for 24 activities.

In FAHP method, input values, i.e. PVs for both likelihood and impact are smaller because total of all PVs for likelihood and PVs for impact for all activities (N), should be 1 in both cases, whereas in MEVM and FEVM the values of likelihood or impact range from 0 to 1. Hence when the number of activities is more than 20, PV of likelihood or PV of impact for each activity computed would be smaller. But in case of MEVM or FEVM, likelihood or impact values ranges from 0 to 1; hence, the number of activities does not influence input values of

Table 4 Risk index comparison by MEVM, FEVM and FAHP

Activity	MEVM	FEVM	FAHP
Feasibility and DPR risks (A1)	0.01832	0.03087	0.0074
Risks in tender and award of contract (A2)	0.01464	0.02945	0.0073
Risks in land handover (A3)	0.02963	0.03937	0.0071
Risks in drawing receipt (A4)	0.01573	0.03033	0.0061
Risks in topographical survey works (A5)	0.00722	0.02111	0.0057
Risks in traffic and utility diversion (A6)	0.03369	0.03978	0.0065
Risks in shuttering works (A7)	0.00368	0.02045	0.0065
Risks in casting yard set-up (A8)	0.00957	0.02340	0.0055
Risks in road widening and barricading work (A9)	0.01107	0.02539	0.0071
Risks in casting of test piles (A10)	0.01491	0.02875	0.0065
Risks in segment casting (A11)	0.01783	0.03195	0.0061
Risks in piling works (A12)	0.01343	0.02755	0.0071
Risks in launching girder installation and segment erection (A13)	0.03547	0.03856	0.0065
Risks in pier works (A14)	0.01832	0.03978	0.0074
Risks in pre-stressing (A15)	0.01464	0.03269	0.0073
Risks in post-tensioning (A16)	0.02963	0.03937	0.0071
Risks in construction planning (A17)	0.03369	0.03978	0.0065
Risks in obligatory span (A18)	0.01832	0.03978	0.0074
Risks in span alignment works (A19)	0.01464	0.03269	0.0073
Risks in bearing works (A20)	0.02963	0.03937	0.0071
Risks in parapet casting (A21)	0.03369	0.03978	0.0065
Risks in parapet erection works (A22)	0.03369	0.03978	0.0065
Risks in cable tray (A23)	0.01832	0.03978	0.0074
Risks in expansion joint works (A24)	0.01464	0.03269	0.0073

Fig. 5 Risk index comparison by MEVM, FEVM and FAHP
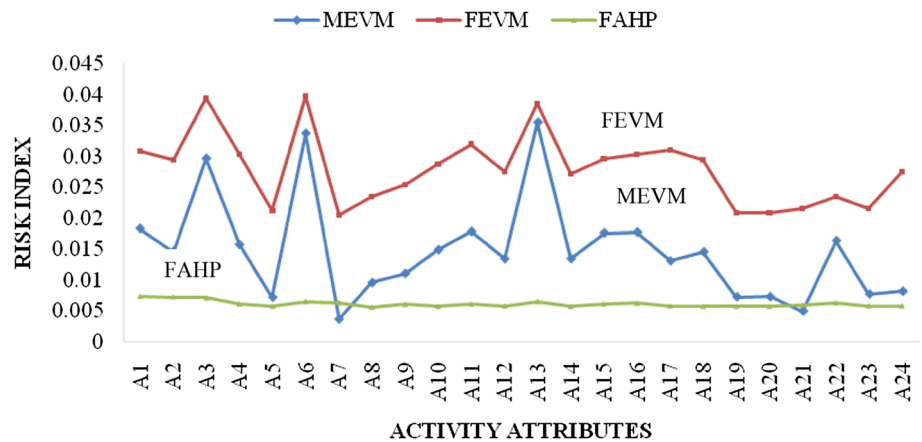
fuzzy and also output of fuzzy in terms of final risk severity values. Hence, the final risk severity values are not affected by the number of activities in case of MEVM or FEVM. Table 5 represents the relative comparison of the different methods of risk analysis.

Conclusion

From the analysis carried out, it has been observed that FAHP method is having very narrow risk severity range (0.140–0.162) and very narrow risk index range (0.0055–0.0074). Also there is overlap of large number of

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Table 5 Relative comparison of the different methods of risk analysis

Methods of risk analysis	Advantages	Limitations
(1) Modified expected value method (MEVM)	(i) Lesser fluctuation in the risk index curve than FEVM	(i) More risk mitigation measures need to be adopted than FAHP
	(ii) Exhibits good risk severity and risk index range than FAHP	(ii) The normalized weight values are very small when numbers of activities are greater than 25
		(iii) Produces good results up to 25 activities
(2) Fuzzy expected value method (FEVM)	(i) Exhibit widest range of risk severity and risk index than MEVM and FAHP	(i) High fluctuation in risk index curve than MEVM and FAHP
	(ii) All identified risks can be ranked according to severity, and suitable mitigation measures can be adopted to reduce the risk severity	
	(iii) Gives good results with any number of activities.	
(3) Fuzzy analytic hierarchy process (FAHP)	(i) Less fluctuation in the risk index curve than MEVM and FEVM	(i) Very narrow risk severity and risk index range
		(ii) Overlap of risk rankings
		(iii) Lesser number of risks can be ranked, and thereby less mitigation measures can be adopted
		(iv) Computed risk index values are very small when the number of activities is greater than 20 and looks insignificant as compared to MEVM and FEVM

risk rankings and only 13 ranks can be obtained for 24 activity risks. MEVM method is having good risk severity range (0.165–0.512) and risk index range (0.00368–0.03547). FEVM method is having widest risk severity range (0.501–0.781) and risk index range (0.01637–0.03978). Further, there is only one overlap of rankings in FEVM and 23 ranks can be obtained for 24 activity risks. It has been observed that in FEVM the computed values of risk indices predict risk severities which can be ranked according to criticality for almost all the identified activities. Thus, project authorities can easily take necessary mitigation measures to reduce the risk severities. In MEVM and FAHP, there may be overlap of rankings based on the risk indices value. Thereby, FEVM is more sensitive than MEVM and FAHP. Also, FEVM produces good results for both small and large number of activities. MEVM gives good results for up to 25 numbers of activities and FAHP gives good results up to 20 numbers of activities. Hence, FEVM appears to be the best suited method for risk management tool for elevated corridor metro rail projects.

It has been found that from MEVM, FEVM and FAHP methods, "risks in launching girder erection", "risks in traffic and utility diversion", "risks in land handover", "feasibility and DPR risks", "risks in segment casting", "risks in tender and award of contract", "risks in pre-stressing" and "risks in road widening and barricading work" have obtained 1–7 ranks based on their risk index values. These activities are very crucial, and therefore, utmost care has to be taken for risk mitigation of these activities. A limitation of this study is that the developed risk indices are dependent on the responses given by the respective respondents through the questionnaire survey. Risk detection parameters were not considered for the study.

Scope for Future Research

Risk detection framework needs to be integrated with the risk analysis methods for better results. As the concept is generic, similar risk indices can be developed for other infrastructure projects like underground corridor metro rail project, highway project, bus rapid transit system project and ports project.

Appendix 1

See Table 6.

Table 6 Sample questionnaire for major activity risks for elevated corridor metro rail project

Name of respondent	Organization		
Designation	Experience		
Risk description	Likelihood (0–1)	Impact (0–1)	Weightage ($\sum W = 1$)
Feasibility and DPR risks (A1)			
Risks in tender and award of contract (A2)			
Risks in land handover (A3)			
Risks in drawing receipt (A4)			
Risks in topographical survey works (A5)			
Risks in traffic and utility diversion (A6)			
Risks in shuttering works (A7)			
Risks in casting yard set-up (A8)			
Risks in road widening and barricading work (A9)			
Risks in casting of test piles (A10)			
Risks in segment casting (A11)			
Risks in piling works (A12)			
Risks in launching girder installation and segment erection (A13)			
Risks in pier works (A14)			
Risks in pre-stressing (A15)			
Risks in post-tensioning (A16)			
Risks in construction planning (A17)			
Risks in obligatory span (A18)			
Risks in span alignment works (A19)			
Risks in bearing works (A20)			
Risks in parapet casting (A21)			
Risks in parapet erection works (A22)			
Risks in cable tray (A23)			
Risks in expansion joint works (A24)			

Appendix 2

See Table 7.

Table 7 Risk index scale and classification

Method	Risk index	Classification
MEVM	0.000–0.00199	Very low risk
	0.00200–0.00359	Low risk
	0.00360–0.01299	Medium risk
	0.01300–0.01769	High risk
	0.01770–1.0000	Critical risk
FEVM	0.000–0.00199	Very low risk
	0.00200–0.00999	Low risk
	0.01000–0.01599	Medium risk
	0.01600–0.02499	High risk
	0.02500–1.0000	Critical risk
FAHP	0.000–0.0009	Very low risk
	0.0010–0.0044	Low risk
	0.0045–0.0055	Medium risk
	0.0056–0.0059	High risk
	0.0060–1.0000	Critical risk

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