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Project Risk Analysis for Elevated Metro Rail Projects using Fuzzy Failure Mode and Effect Analysis (FMEA)

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Mega infrastructure projects are subjected to enormous risks due to pre execution, execution and commissioning activities. Hence there is dire need of systematic risk analysis technique which can identify quantify and analyse these risks and helps in formulation of risk response strategies. This paper is an attempt to compute risk severity by Fuzzy EVM and in order to take risk mitigation measures (Detection tools) for all the major activities of the elevated corridor metro rail project using Fuzzy FMEA (Failure Mode and Effect Analysis). EVMand FMEA are structured techniques that can help in identifying the risk for the major activities of a project. Fuzzy logic is incorporated within EVM andFMEA to map the interrelationship between input parameters of EVM and FMEA like probability, impact and detection (control)of that risk for a certain activity. Case study of Ahmedabad metro rail project is undertakenby considering pre execution activities (feasibility, DPR and design etc.) and execution phase (contracts, tendering, construction planning, segment casting, segment erection, utility & traffic diversion etc.) to validate the concept of fuzzy EVM and fuzzy FMEA methods.

Keywords: Project risk analysis; metro rail project; likelihood; impact; detection;Fuzzy; Severity; Expected Value Method (EVM); Failure Mode and Effect Analysis (FMEA)

Introduction

In recent years, intensive research and development has been done in the area of Project Risk Management. It is extensively recognised as one of the most critical procedures and capability areas in the field of project management. The construction industry, perhaps more than others has been afflicted by risk and resulting in very poor performance with increasing costs and time delays. Every part of project life cycle is subject to risks, which have to be treated effectively to achieve its goals in an optimal way.

Sarkar and Dutta (2011) developed a comprehensive risk management model for underground corridor construction for metro rail operations.. They have evaluated these risks in terms of likelihood and impact.

Oliveros and Fayek (2005) presents a fuzzy logic model for site progress and delays reporting, with a schedule updating and forecasting system for construction project monitoring and control Eom and Paek (2009) developed an environmental risk index model for general contractors to minimize third-party environmental disputes at construction sites.

Subramanyam et al. (2012) have focused on research work to identify factors that influence the smooth completion of a project and develop a risk assessment model.. A total of 93 risk factors were identified and listed under various subgroups in this paper.

Kuo and Lu (2012), have expressed their views in undertaking of construction projects in metropolitan areas is a risky, competitive, and dynamic proposition requiring a reliable risk assessment model for adequate planning. Subramanyam et al. (2012) took the quantitative model which is developed on the basis of the probability of occurrence of a risk and its level of significance. Chan et al. (2009) comprehensively review the fuzzy literature that has been published in eight selected top quality journals in 10 years.

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Methodology

Expected Value Method (EVM):

Sarkar and Dutta (2011) had used EVM by extending the work of Nicholas (2007). They defined the variables as follows;

L_i : Likelihoodofi^{th}risksourcefor j^{th}activity

W_i : Weightageof i^{th}risksourceforj^{th}activity

I_i : Impactofi^{th}risksourceforj^{th}activity

CLF_j: CompositeLikelihoodFactor forj^{th}activity

CIF_j: CompositeImpactFactorforj^{th}activity

Thecorrespondingweightage(W_i)ofeachactivityhasalsobeenobtainedfromthe feedbackofthequestionnairesurveycirculatedamong experts.

$$\sum_{i=1}^{m} W_i = 1 f \qquad (j = 1 \ldots \ldots n)(1)$$

TherelationshipofcomputingtheCLF and CIFasaweightedaverageisgivenbelow:

$$C \quad L \quad ho \quad F \quad (C \quad)_j = \sum_{i=1}^{m} L_i . W_i \; f \quad a \quad j \,(2)$$

$$C \quad I \quad F \quad (C \quad)_j = \sum_{i=1}^{m} I_i . W_i \; f \quad a \quad j \,(3)$$

$$0 \le I_i \le 1 \sum_{i=1}^{m} W_i \; f \quad a \quad j$$

The data collected from 66 experts to be analysed using EVM. The data from 66 experts in 24 appendices (major risk categories) to be entered in the excel spread sheet to generate risk weights, likelihood of failures of the identified risks and risk impact values ranging from 0 to 1 for each attribute. After that CIF and CLF are to be calculated for each attribute using equations 2 and 3.

*Application of Fuzzy in Expected Value Method (FEVM):*To convert each linguistic variable into fuzzy values, there is a need to define one membership function for all risk factors. The membership functions need to be defined with triangular fuzzy numbers. The computation with triangular fuzzy is relatively simple in comparison with trapezoidal fuzzy. The membership functions are defined with values “Very Low (VL)”, “Low (L)”, “Medium (M)”, “High (H)”, and “V. High (VH)” according to their likelihood and their impact of risk. The values of the linguistic scale are chosen from 0 to 1 at an increment of 0.25. The values of likelihood and their impact of risk ranges from 0 to 1. The severities of the identified risks are to be described in both qualitative and quantitative terms.

Risk Assessment by Fuzzy Failure Mode and Effect Analysis (FMEA)

Abdelgawad and Fayek (2010) explained that, Failure Mode and Effect Analysis(FMEA) is one of the popular risk analysis techniques recommended by international standards. FMEA is a technique that is based on identifying potential failures, analysing root causes, and examining failure impacts so that these impacts can be reduced. Within the context of the traditional FMEA, the degree of criticality of a failure mode is determined by calculating the risk priority number (RPN). The RPN ranges from 1 to 1,000 and is an index score calculated as the product of the severity (S), occurrence (O), and detection (D) of a failure mode. System components that are assessed to have a high RPN are assumed to be more critical than those with lower values. The severity (S) rating is used to represent the potential effects associated with the occurrence of a failure mode. Thus, it reflects the seriousness of the effects of the failure.

Mecca and Masera, (1999) also stated that, FMEA technique could be the most important tool in managing quality plans to obtain a suitable and adequate and subsequently more efficient system to build in conformity with specifications

Sarkar and Bhavnani (2014) explained that, due to increase in project size and complexity, high levels of risk and uncertainty are encountered. Failure Mode and Effect Analysis (FMEA) is one of the risk analysis techniques based on identifying potential failures, analyzing root causes, and examining failure impacts so that these impacts can be reduced.

Failure Mode and Effects Analysis (FMEA) is a risk management and planning technique that can be used to identify and prioritize potential errors/failures within a project/system/process and come up with possible solutions to avoid these errors. (Sawhney et al. 2010)

Carbone and Tippett (2004) introduced an application of FMEA to the context of project risk management by calculating the RPN to find out the most critical events that require immediate response. This calculation is straightforward and easy to understand. But, Bowles and Pelaez (1995) and Puente (2002) noted shortcomings within this RPN calculation. For instance, a failure mode with severity, occurrence, and detection values as 7, 3, and 5 respectively give RPN as 105. Whereas, a failure mode with S, O, and D values 3, 7, and 7 respectively give RPN as 147. So, the latter failure mode shall be considered to establish the response. But, from Management perspective, the S rating for the former mode is higher, which cannot be neglected.

Sarkar and Bhavnani (2014) concluded that, by applying FMEA along with fuzzy logic, it becomes quite convenient to gauge the magnitude of each risk factor for the feasibility, design, and implementation phase of elevated corridor project.

Ayyub (2003) stated that without linking the value of RPN to linguistic terms describing the priority to take corrective actions, the project team will not be able to recognize the difference between the closer values of RPN.

Methodology

The approach taken to develop the fuzzy FMEA expert system by Abdelgawad and Fayek (2010) described in the following steps;

Step 1: Linguistic definition of Occurrence, Impact, and Detection: This step integrates fuzzy logic and FMEA in terms of membership functions for each variable. For this study, 5 point Likert scale have been selected.

Table 1. Linguistic Terms for Severity (S), Occurrence (O) & Detection (D)

Range for S,O &D	Linguistic Terms
1	Very Low
2	Low
3	Medium
4	High
5	Critical

Step 2: Determination And linguistic Definition of Risk Priority Number (RPN): Risk priority number is computed as the product of S, O and D. The higher the RPN, severe is the risk according to FMEA.

Step 3: Apply Fuzzy Logic over Input Parameters using MATLAB: The software used for analysis is MATLAB, which would help in performing fuzzy logic, the steps for which are (1) fuzzification, (2) fuzzy inference, and (3) defuzzification.

Step 4: Establish Membership Functions (MFs) For S, O and D, and RPN: For this study, triangular membership functions are used as described below. Membership functions for each of the input parameters are calculated to validate the various responses.

Step 5: MF definition For S, O and D, and RPN: After calculating membership functions for the input factors, the next step shall be to define these membership functions for their various values between 0 and 1, which shall also help in formulation of mitigation strategies.

Step 6: Mitigation strategy formulation: Based upon the MF definition for the inputs variables and RPN, various mitigation strategies are suggested. The MFs having values higher than certain specified value fall in the area of response strategy formulation.

Step 7: Hybrid Model formulation: The last step is to formulate a conceptual model for risk analysis using FMEA and Combined Fuzzy FMEA.

Table 2. Linguistic Terms for Membership Functions (MFs)

Value of Membership Functions	Linguistic Terms
0.0 to 0.10	Low
0.11 to 0.20	Medium
0.21 to 0.30	High
0.31 to 0.40	Very High
0.41 to 1.00	Critical

Case Study

The case study considered for this study is Ahmedabad elevated metro construction project from the Gyaspur depot to Shreyas station. The length of the stretch is 4.6 kms.The numbers of elevated stations are four (APMC, Jivraj, Rajiv Nagar and Shreyas). The construction is being executed by IL & FS Company Limited. Total 550 piles and 136 piers would be constructed. Total segments to be produced, erected and launched for the viaduct from Gyaspur depot to Shreyas station are 1320 numbers and weight of each segment is 15 tons. IL & FS Company Limited had started piling and pier construction on APMC and Jivraj road. The methodology as discussed was to compute risk severity and were used as inputs for formulating further risk mitigation steps.

Result of the research

The CLF and CLF values obtained from EVM method for all 24 major risk categories were used as inputs for fuzzy method by using Matlab software (Mathworks.Matlab.R2010a). Five membership functions and 25 rules were created in software. The outputs are obtained for all 24 major risk categories as risk severity value. Table 3 represents the final values of CLF and CIF for 4 major risks out of 24 major risks of the elevated corridor construction project. Figure 1 represents the Matlab representation for risk severity for activity “tender and award of contract”.

Table 3. Final values of CLF and CIF for 4 major risk categories

S.NO	Description of project risk (activity)	Composite Likelihood Factor (CLF)	Composite Impact Factor (CIF)
1	Feasibility and DPR risks	0.418	0.685
2	Risks in tender and award of contract	0.348	0.720
3	Risks in Land handover	0.370	0.740
4	Risks in Drawing receipt	0.236	0.661

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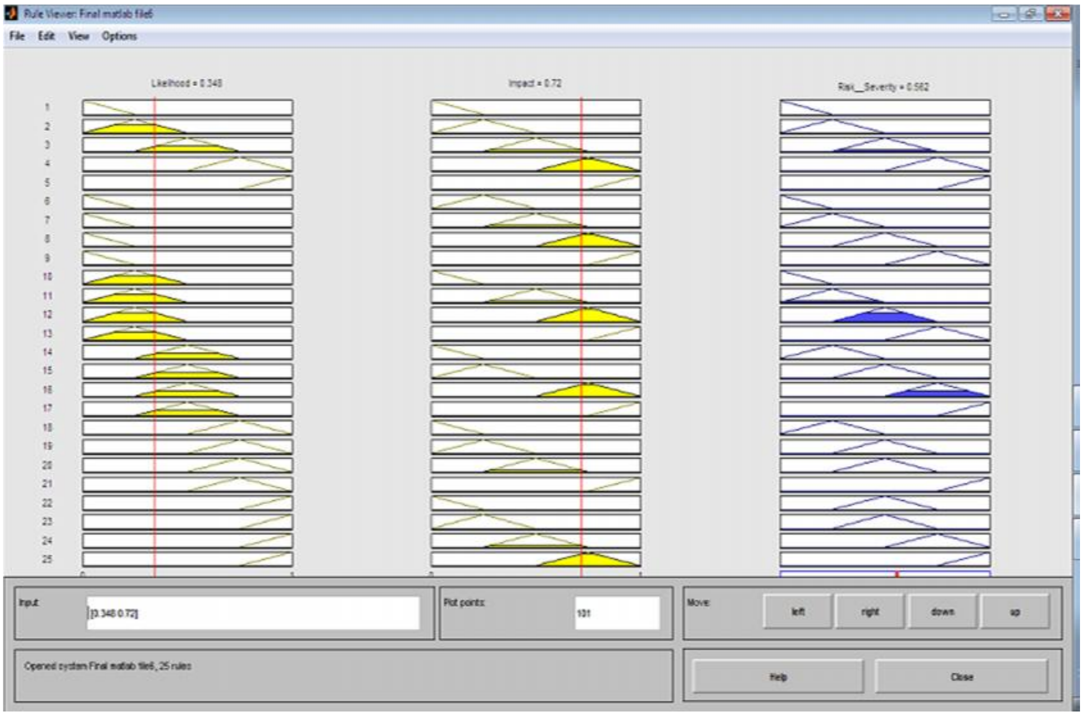

Figure 1 Matlab Representation for Risk Severity for Activity “Tender and Award of Contract

The values of the final risk severities of the all 24 major risks from the identified activities involved in construction of elevated corridor metro rail are calculated and top 6 major risk categoriesare presented in Table 4.

Table 4. Final Risk Severity values (Quantitative & Qualitative) and Ranking using the Concept of Fuzzy EVM for 6 major risk categories

S.NO	Description of project risk (activity)	Final Risk Severity (Fuzzy Value)		Fuzzy EVM Ranking
		Quantitative	Qualitative	
1	Risks in segment erection	0.750	Very High Risk	1
2	Risks in Land handover	0.606	Very High Risk	2
3	Feasibility and DPR risks	0.572	Very High Risk	3
4	Risks in tender and award of contract	0.562	Very High Risk	4
5	Risks in pile test	0.528	Very High Risk	5
6	Risks in Construction programme planning	0.503	Very High Risk	6

The likelihood, impact and detection values were obtained fromexperts through questionnairesurveycirculatedamong expertsof elevated metro rail corridor project for all 24 major risk categories were used as inputs for Fuzzy method by using Matlab software. Five Membership functions and 125 rules were created in software. The outputs are obtained for all 24 major risk categories as risk priority number. All values are calculated and tabulated for 4 major risk categoriesin Table 5.

Table 5. Final Fuzzy values of RPN for 4 major risk categories

S.NO	Description of project risks	(S)	(O)	(D)	Fuzzy RPN
1	Feasibility and DPR risks	0.286	0.418	0.843	0.662
2	Risks in tender and award of contract	0.25	0.348	0.814	0.603
3	Risks in Land handover	0.274	0.370	0.833	0.623
4	Risks in Drawing receipt	0.156	0.236	0.643	0.368

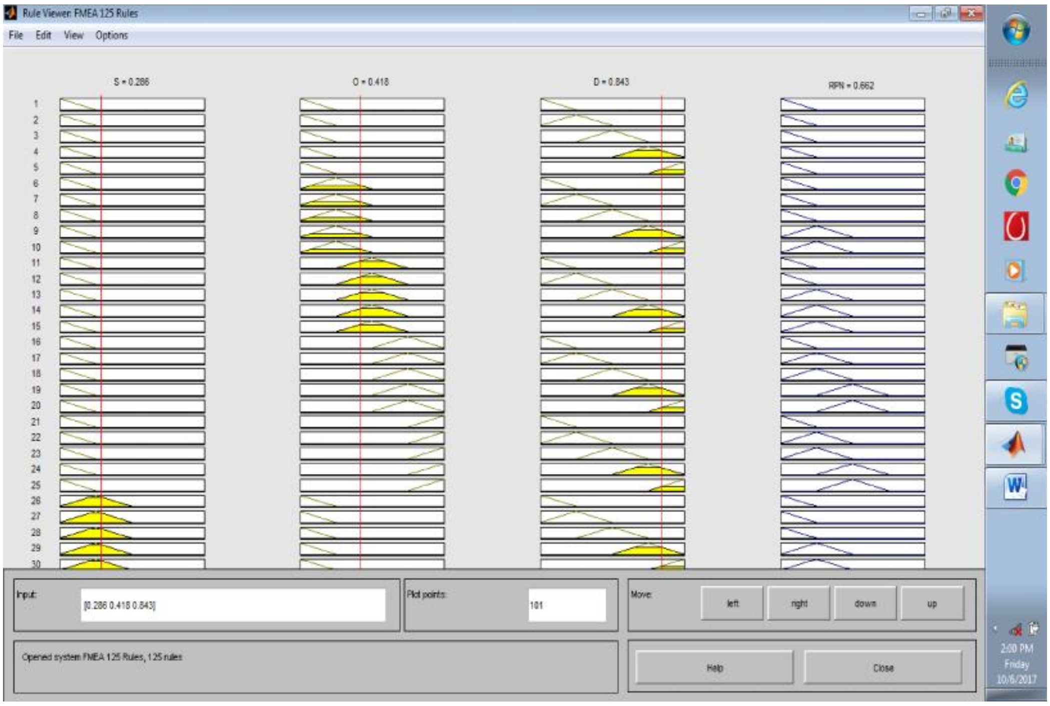

Figure 2. Fuzzy Risk Priority Number (FRPN) for Feasibility and DPR activity

Table 6. Final FRPN values and fuzzy FMEA rankings for top 7 major risk categories

S.NO	Description of project risk (activity)	Final Risk Priority Number (Fuzzy Value)		Fuzzy FMEA Ranking
		Quantitative	Qualitative	
1	Feasibility and DPR risks	0.662	Very High Risk	1
2	Risks in Land handover	0.623	Very High Risk	2
3	Risks in tender and award of contract	0.603	Very High Risk	3
4	Risks in segment erection	0.520	Very High Risk	4
5	Sub structure work to super structure work risks	0.448	Very High Risk	5
6	Risks in segment erection	0.416	Very High Risk	6
7	Risks in Obligatory span	0.401	Very High Risk	7

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Discussion and Interpretation

The final qualitative risk severity obtained by FEVM and risk priority numberobtained by Fuzzy FMEA for all 24 major risk categories of an elevated metro corridor project are tabulated in Table 7.

Table 7. Comparison of Fuzzy EVM and Fuzzy FMEA for top 15 major risk categories

FUZZY EVM				FUZZY FMEA	
S.NO	**Description of Project Risk category (activity)**	**Final Risk Severity (Qualitative)**	**Fuzzy Rank**	**Final Risk Priority Number (Qualitative)**	**Fuzzy FMEA Rank**
1	Risks in segment erection	Very High Risk	1	Very High Risk	4
2	Risks in land handover	Very High Risk	2	Very High Risk	2
3	Feasibility and DPR risks	Very High Risk	3	Very High Risk	1
4	Risks in tender and award of contract	Very High Risk	4	Very High Risk	3
5	Risks in pile test	Very High Risk	5	Very High Risk	5
6	Risks in construction programme planning	Very High Risk	6	High Risk	8
7	Risks in topographical survey	Very High Risk	7	High Risk	12
8	Risks in launching girder	High Risk	8	High Risk	9
9	Risks in obligatory span	High Risk	9	Very High Risk	7
10	Risks in pile test -Risks in road widening and barricading work	High Risk	10	High Risk	10
11	Risks in expansion joint	High Risk	11	High Risk	14
12	Risks in segment casting	High Risk	12	Very High Risk	5
13	Sub structure work to super structure work risks	High Risk	13	Very High Risk	5
14	Risks in road widening and barricading	High Risk	14	Medium Risk	18
15	Risks in pile test- Casting of test pile	High Risk	15	High Risk	16

In this table,top 15 major risk categoriesout of 24, of an elevated metro corridor project are tabulated for both methods from ranking 1 to 24 w.r.t final risk severity and RPN values obtained. And for comparison purpose, the final risk severity and RPN values for same activity is also tabulated in Table 7 with rank obtained from FEVM and Fuzzy FMEA methods. For example, By Fuzzy EVM method, Risks in segment erectionis very high and Fuzzy EVM ranking is one, while qualitative risk priority is very high and ranking is 4 by Fuzzy FMEA method.Risks in land handover is very high and Fuzzy EVM ranking is 2, while same activity also comes under very high risks and ranking is also 2 by Fuzzy FMEA. Risks in construction programme planning is very high and Fuzzy EVM ranking is 6, while same activity comes under high risks and ranking is 8 by Fuzzy FMEA. Likewise comparison has been done (Pl refer Table 7.)

Conclusion

It is concluded that, Feasibility and DPR, Land hand over, Tender and award of contract, construction programme planning, launching girder and obligatory span activities are found very risky in both of the methods and are having very high to high risk severity and RPN value. Hence risk mitigation measures by authorities should be taken accordingly.

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