# Comparative study of EVM and Fuzzy EVM Methods for Risk Analysis of Infrastructure Transportation Project

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## Abstract

***Mega infrastructure projects are subjected to countless risks due to its distinctive features in pre –execution phase (like feasibility, design etc.), execution and implementation phase. So, a very systematic process of risk analysis is essential for the classification, identification, computation and analysis of all these risks, and to articulate risk response strategies. This paper is an attempt to compute risk severity of the elevated corridor metro rail project using Expected Value Method and Fuzzy EVM (Expected Value Method) and conduct the comparative study of both methods. Ranking of major activities of elevated metro corridor project is done by using both EVM and Fuzzy EVM Method. The significance of this present research work lies in developing a project risk analysis model by application of Fuzzy Expected Value Method (FEVM) tool. This tool is a modification over conventional Expected Value Method (EVM) for project risk analysis. This application would provide base to take risk mitigation measures according to priority of risks, hence improvement in decision making.***

**Keywords:** Risk severity, Membership functions, Expected Value Method, FEVM, Risk assessment

## 1. INTRODUCTION

Over the past 60 years, countless mega infrastructure projects like construction of metro rail corridors, tunnels, bridges, airports, ports etc. have experienced large variations in cost and schedule causing huge amount of delays in the execution and commissioning of these projects. Due to increase in project complications and magnitudes, high levels of uncertainties and risks are encountered through all the phases of the project starting from pre–execution phase like feasibility, land acquirement, Government approvals etc. to execution phase like award of tenders, design, development, site execution and final commissioning phase. These risks and uncertainties causes' terrific time and cost overrun which ultimately affects successful accomplishment of the project. Mass Rapid Transit System projects like execution of underground and elevated metro rail projects encompass very high degree of risks during the process of land acquisition, tendering and contracts, design, piling, pier, casting and erection of segments, launching girder pre-stressing operations. This paper aims at computation of risk severity and risk rankings of the major activities involved in elevated corridor metro rail operations through Expected Value Method and Fuzzy EVM (Expected Value Method) and conduct the comparative study of both methods. This risk severity and ranking would help to classify the risks according to priority, thus enabling the project authorities to formulate risk mitigation measures accordingly.

Sarkar and Dutta (2011) developed a broad risk management model for underground corridor construction for metro rail operations. The process of risk management was carried out throughout the entire phases of the project starting from feasibility, design, development to implementation. The identification of the risks was carried out by the personal experience of the authors and by interacting with the experts associated with similar projects. Jannadi and Almishari (2003) had developed model for risk assessment by using concepts of likelihood and severity of impact. However, risk ranking methodology was not framed. Abdelgawad and Fayek (2010) had developed fuzzy FMEA and Fuzzy AHP model which is very useful and practical for the assessment of the level of criticality of risk events in the construction projects. Choi et al. (2004) had developed fuzzy based uncertainty model for subway construction projects in Korea. Eom and Paek (2009) developed an environmental risk index model for general contractors to minimize third-party environmental disputes at construction sites. Chan et al. (2009) had reviewed the fuzzy literature from 1996 to 2005, which were published in top journals. Li and Zou (2011) had developed Fuzzy AHP based risk assessment methodology for Public Private Partnership projects. Subramanyam et al. (2012) have identified 93 risk factors and listed under various subgroups. Kuo and Lu (2013), have expressed their views about construction projects in metropolitan areas.

They highlighted that due to the highly risky, competitive, and dynamic proposition there is a requirement for a reliable risk assessment model for adequate project planning. Subramanyam et al. (2012) took the quantitative model which was developed on the basis of the probability of occurrence of a risk and its level of significance. The weight scale is chosen from 0 to 9, in which 0 corresponds to no risk situation, and 9 corresponds to highest probability of occurrence of risk. Similarly, 0 corresponds to a low level of risk, and 9 correspond to the highest level of risk. 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. Sarkar and Bhavnani (2014) explained that, over the past decades, many complex mega infrastructure projects like construction of elevated and underground corridors for metro rail, etc. have experienced large variations in cost and schedule causing huge amount of delays in the execution and commissioning of these projects. Due to increase in project size and complexity, high levels of risk and uncertainty are encountered.

## 2. METHODOLOGY

### 2.1 Risk Assessment by Expected Value Method (EVM)

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

$L_{ij}$ : Likelihood of $i^{th}$ risk source for $j^{th}$ activity

$W_{ij}$: Weightage of $i^{th}$ risk source for $j^{th}$ activity

$I_{ij}$ : Impact of $i^{th}$ risk source for $j^{th}$ activity

$CLF_j$: Composite Likelihood Factor for $j^{th}$ activity

$CIF_j$: Composite Impact Factor for $j^{th}$ activity

An activity may have several risk sources each having its own likelihood of occurrence and impact of risk. The likelihood of failure ($L_{ij}$) and impact ($I_{ij}$ ) defined above, of the identified risk sources of each activity were obtained through a questionnaire survey. The target respondents were experts and professionals involved in and associated with the project under analysis and also other similar projects. The corresponding weightage ($W_{ij}$) of each activity has also been obtained from the feedback of the questionnaire survey circulated among experts.

$$\sum_{i=1}^{M} W_{ij} = 1 \; for\ all\ j \; (j = 1 \ldots \ldots N) \ldots \ldots . . (1) \; Sarkar\ and\ Dutta\ (2011)$$

The weightages can be based on local priority where the weightages of all the sub- activities of a particular activity equal 1.The mean of all the responses should be considered for analysis. Inconsistent responses can be modified using the Delphi technique. The likelihood ($L_{ij}$) of all risk sources for each activity j can be combined and expressed as a single composite likelihood factor ($CLF_j$). The weightages ($W_{ij}$) 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:

$$Composite\ Likelihood\ Factor\ (CLF)_j = \sum_{i=1}^{M} L_{ij}.W_{ij} \; for\ all\ j \ldots \ldots . (2) \; Sarkar\ and\ Dutta\ (2011)$$

$$Composite\ Impact\ Factor\ (CIF)_j = \sum_{i=1}^{M} I_{ij}.W_{ij} \; for\ all\ j \ldots \ldots . (3) \; Sarkar\ and\ Dutta\ (2011)$$

$$0 \leq \; I_{ij} \; \leq 1 \sum_{i=1}^{M} W_{ij} \; for\ all\ j$$

The data collected from 51 experts to be analysed using EVM. The data from all experts in 22 major risk activities 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.

### 2.2 Risk Assessment by Fuzzy EVM (FEVM)

For the conversion of each linguistic variable into fuzzy values, one membership function for all risk factors has to be defined. The calculations with triangular fuzzy are relatively simple in comparison with trapezoidal fuzzy. Therefore membership functions has to be defined with triangular fuzzy numbers. The membership functions are defined with values "Very Low (VL)", "Low (L)", "Medium (M)", "High (H)", and "Very High (VH)" according to their likelihood and their impact of risk. The values of the linguistic scale are chosen from 0 to 5.The values of likelihood and their impact of risk ranges from 0 to 1. Please refer Annexure-1 for linguistic scale for likelihood and Impact of Risk (Risk Severity Classification).The severity risk is to be described both qualitative and quantitative.

## 3. CASE STUDY

The case study considered for this study is Ahmedabad elevated corridor construction for metro rail operations starting from the Vastral Gaam to Apparel Park section. The length of the corridor is 6 kms of the Metro's 20.536 km East-West line and the numbers of elevated stations are four (Nirant cross road, Vastral, Rabari colony and Amraiwadi). The construction is being executed by J.Kumar infra projects company. Total segments to be produced, erected and launched for the viaduct from Vastral Gaam to Apparel Park section are 2100 numbers and weight of each segment is 14 tons. J Kumar Infra projects started launching precast segments in the Nirant Cross Roads area to construct a portion of Ahmedabad Metro's viaduct. This activity started exactly a year after they won the contract to build the 6 km stretch of Vastral Gam to Apparel Park section of the East-West line. The cost of construction is approximately 280 crores excluding stations. The project duration for construction is 27 months. The methodology as discussed was primarily formulation of data questionnaire survey where the responses of the respondents from the officials of metro rail were used as inputs for computing the risk severities and rankings of all major activities. Hence, first work was to identify the major activities involved from the starting of the project primarily from pre-execution phase to commissioning phase. For each activity, risks involved were identified after 2-3 rounds of discussions with metro officials and staff including operators, foreman, contractors, sub- contractors, consultants and other field experts. The risk assessment was made primarily in terms of severity level both quantitative and qualitative.

## 4. RESULTS

### Final Risk Severity and Ranking by EVM method

The CLF and CLF values are computed for each attribute using equations 2 and 3 for all the 22 major risk categories. Table 1 represents the final values of CLF and CIF for 13 major risks of the metro rail corridor project. After that final risk severity values are calculated for all the 22 major risk categories by multiplication of CLF and CIF values of each activity (Please refer table 2).

**Table 1**: Final values of CLF and CIF for 13 major risk categories of metro rail project

| Sr. No. | Description of project risk (activity) | Composite Likelihood Factor (CLF) | Composite Impact Factor (CIF) |
|---|---|---|---|
| 1 | Risks in shuttering Design | 0.300 | 0.600 |
| 2 | Risks in casting yard setup | 0.190 | 0.630 |
| 3 | Risks in sub structure works to super structure works (pile, pile cap, pier, pier cap) | 0.290 | 0.730 |
| 4 | Risks in segment casting | 0.260 | 0.700 |
| 5 | Risks in launching girder | 0.290 | 0.745 |
| 6 | Risks in Topographical survey | 0.190 | 0.790 |
| 7 | Risks in traffic and utility diversion | 0.450 | 0.700 |
| 8 | Risks in segment erection | 0.430 | 0.740 |
| 9 | Risks in road widening and barricading | 0.190 | 0.700 |
| 10 | Risks in span alignment and bearing | 0.215 | 0.640 |
| 11 | Risks in Parapet casting | 0.190 | 0.615 |
| 12 | Risks in Parapet erection | 0.210 | 0.680 |
| 13 | Risks in Cable tray and Expansion joints | 0.225 | 0.660 |

**Table 2**: Final risk severity values and Ranking using the concept of EVM for eight identified risks

| Sr. No. | Description of project risk (activity) | Final Risk Severity (EVM method) | | EVM Ranking |
|---|---|---|---|---|
| | | Quantitative | Qualitative | |
| 1 | DPR risks | 0.340 | Very High Risk | 1 |
| 2 | Risks in segment erection | 0.318 | Very High Risk | 2 |
| 3 | Risks in traffic and utility diversion | 0.315 | Very High Risk | 3 |
| 4 | Risks in land handover | 0.300 | Very High Risk | 4 |
| 5 | Feasibility risks | 0.287 | Very High Risk | 5 |
| 6 | Risks in sub structure works to super structure works (pile, pile cap, pier, pier cap) | 0.281 | Very High Risk | 6 |
| 7 | Risks in tendering and award of contracts | 0.252 | Very High Risk | 7 |
| 8 | Risks in launching girder | 0.216 | Very High Risk | 8 |

**Final Risk Severity and Ranking by EVM method**

The Composite Likelihood Factor (CLF) and Composite Impact Factor (CLF) values obtained from EVM method for all 22 major risk categories were used as inputs for Fuzzy method by using Matlab software. Five Membership functions and 25 rules were created in software. The fuzzy outputs are obtained for all 22 major risk categories as risk severity value. For example: Final Risk severity in land handover activity is shown in figure 1.

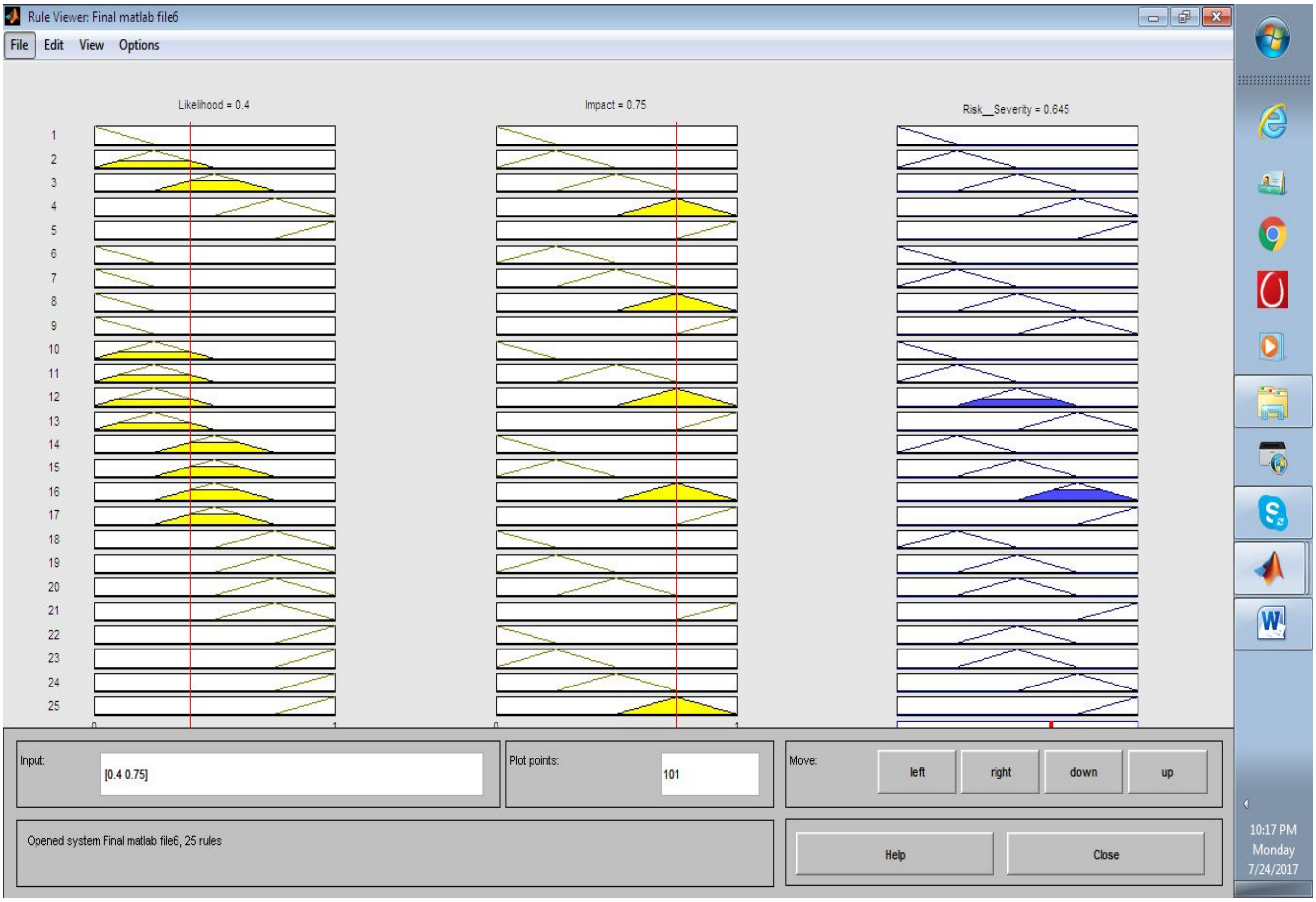


**Figure 1** Final Risk severity in land handover activity

The Risk severity values and rankings for all 22 major risk categories are computed. The Risk severity values and rankings for 12 major risk categories are tabulated in table 3.

**Table 3**: Final Risk Severity values and Ranking using the Concept of Fuzzy EVM for 12 major risk categories

| Sr. No. | Description of project risk (activity) | Final Risk Severity (Fuzzy Value) | | Fuzzy EVM Ranking |
|---|---|---|---|---|
| | | Quantitative | Qualitative | |
| 1 | Risks in Detail Project Report (DPR) | 0.658 | Very High Risk | 1 |
| 2 | Risks in segment erection | 0.653 | Very High Risk | 2 |
| 3 | Risks in land handover | 0.645 | Very High Risk | 3 |
| 4 | Risks in traffic and utility diversion | 0.610 | Very High Risk | 4 |
| 5 | Risks in Sub structure works (pile & pile cap) to super structure works (pier & pier cap) | 0.603 | Very High Risk | 5 |
| 6 | Risks in feasibility | 0.571 | Very High Risk | 6 |
| 7 | Risks in tendering and contracts | 0.564 | Very High Risk | 7 |
| 8 | Risks in topographical survey | 0.552 | Very High Risk | 8 |
| 9 | Risks in launching girder | 0.543 | Very High Risk | 9 |
| 10 | Risks in pile test | 0.529 | Very High Risk | 10 |
| 11 | Risks in construction programme planning | 0.514 | Very High Risk | 11 |
| 12 | Risks in pile test- Risks in road widening and barricading work | 0.461 | High Risk | 12 |

## 5. DISCUSSION & INTERPRETATION

The final quantitative and qualitative risk severity values along with rankings for all the 22 major identified risk categories of an elevated metro rail project computed by EVM and Fuzzy EVM are tabulated in table 4. By EVM method, DPR activity is having highest quantitative risk severity values of 0.340 and EVM ranking is one. After applying Fuzzy i.e. by Fuzzy EVM method, DPR activity is having very high risk severity values both quantitative and qualitative and ranking is one. The risks in segment erection are very high and falls under having very high risk severity category both by EVM and Fuzzy EVM methods and ranking obtained as two. Risks in Land handover activity for an elevated metro corridor project stood third rank by Fuzzy EVM method and is having quantitative risk severity values of 0.645. Risks severity values both quantitative and qualitative in Land handover activity are very high. Risks in traffic and utility diversion are having high severity risks by EVM method and ranking is 3.While risks in traffic and utility diversion are having high severity values by Fuzzy EVM method and ranking is 4. The feasibility activity is having very high risks and risk severity rankings are 5 and 6 by EVM and fuzzy EVM methods respectively. Risks in tender and award of contract activity are very high both quantitative and qualitative and ranking is 3 by EVM, while same activity come under very high risks and ranking is 4 by Fuzzy EVM. By EVM method, risks in launching girder, piles, piers, tendering and contracts, feasibility, DPR, traffic and utility diversions come under very high risk severity category and all these works are to be planned and executed very very carefully. By Fuzzy EVM method, 3 more risks falls under very high risk severity category such as topographical survey, construction planning and testing of piles. There is good range of risk severity quantitative values from 0.367 to 0.658 obtained by Fuzzy EVM method. In case of EVM, range of risk severity quantitative values is very narrow from 0.117 to 0.340 for all 22 major risk categories of an elevated metro corridor project. There is clear risk severity ranking for all 22 major risk categories of an elevated metro corridor project by Fuzzy EVM method (Pl refer table 4).But there is overlap of risk ranking for segment casting and construction planning activities of an elevated metro corridor project by EVM method. Both have same risk severity ranking as 9 (Pl refer table 4) and risk severity value is 0.182 for both activities. But as per practical experience of experts and by Fuzzy EVM, It was concluded that Risks in construction planning are more critical than segment casting and it is supported by risk severity values of 0.514 and 0.454 respectively for construction planning and segment casting. By EVM method, Risks in parapet erection are having medium severity risks while by Fuzzy EVM method, Risks in parapet erection are having high severity risks which is true as per experts opinion and practical site conditions (mainly due to work at height safety issues).

**Table 4**: Comparison of Qualitative Risk Severity values and Fuzzy Ranking using the Concept of Fuzzy EVM and EVM

| EVM | | | | FUZZY EVM | | |
|---|---|---|---|---|---|---|
| **Sr. No.** | **Description of Project Risk category (activity)** | **Final Risk Severity (Qualitative)** | **EVM Rank** | **Description of Project Risk category (activity)** | **Final Risk Severity (Qualitative)** | **Fuzzy EVM Rank** |
| 1 | Risks in DPR | Very High Risk | 1 | Risks in DPR | Very High Risk | 1 |
| 2 | Risks in segment erection | Very High Risk | 2 | Risks in segment erection | Very High Risk | 2 |
| 3 | Risks in traffic and utility diversion | Very High Risk | 3 | Risks in land handover | Very High Risk | 3 |
| 4 | Risks in land handover | Very High Risk | 4 | Risks in traffic and utility diversion | Very High Risk | 4 |
| 5 | Risks in feasibility | Very High Risk | 5 | Risks in Sub structure works to super structure works | Very High Risk | 5 |
| 6 | Risks in Sub structure works (pile & pile cap) to super structure works (pier & pier cap) | Very High Risk | 6 | Risks in feasibility | Very High Risk | 6 |
| 7 | Risks in tendering and contracts | Very High Risk | 7 | Risks in tendering and contracts | Very High Risk | 7 |
| 8 | Risks in launching girder | Very High Risk | 8 | Risks in topographical survey | Very High Risk | 8 |
| 9 | Risks in construction programme planning | High Risk | 9 | Risks in launching girder | Very High Risk | 9 |
| 10 | Risks in segment casting | High Risk | 9 | Risks in pile test | Very High Risk | 10 |
| 11 | Risks in shuttering design | High Risk | 10 | Risks in construction programme planning | Very High Risk | 11 |
| 12 | Risks in drawing receipt | High Risk | 11 | Risks in pile test- Risks in road widening and barricading work | High Risk | 12 |
| 13 | Risks in pile test- Risks in road widening and barricading work | Medium Risk | 12 | Risks in segment casting | High Risk | 13 |
| 14 | Risks in topographical survey | Medium Risk | 13 | Risks in road widening and barricading | High Risk | 14 |
| 15 | Risks in cable tray & expansion joint | Medium Risk | 14 | Risks in shuttering design | High Risk | 15 |
| 16 | Risks in parapet erection | Medium Risk | 15 | Risks in parapet erection | High Risk | 16 |
| 17 | Risks in pile test- casting of test pile | Medium Risk | 16 | Risks in pile test- casting of test pile | High Risk | 17 |
| 18 | Risks in pile test | Medium Risk | 17 | Risks in cable tray & expansion joint | High Risk | 18 |
| 19 | Risks in span alignment and bearing | Medium Risk | 18 | Risks in drawing receipt | High Risk | 19 |
| 20 | Risks in road widening and barricading | Medium Risk | 19 | Risks in span alignment and bearing | Medium Risk | 20 |
| 21 | Risks in casting yard setup | Medium Risk | 20 | Risks in casting yard setup | Medium Risk | 21 |
| 22 | Risks in parapet casting | Medium Risk | 21 | Risks in parapet casting | Medium Risk | 22 |

## 6. CONCLUSION

There is clear risk severity ranking and more practical / field oriented results for all 22 major risk categories of an elevated metro corridor project by Fuzzy EVM method. There is good range of risk severity quantitative values from 0.367 to 0.658 obtained by Fuzzy EVM method. In case of EVM, range of risk severity quantitative values is very narrow from 0.117 to 0.340 for all 22 major risk categories of an elevated metro corridor project.

After analysis of results and discussions with subject experts, it is concluded that although Expected Value Method is being generally used for the analysis of risks by using the composite likelihood factor and composite impact factor concept. But interrelationship between the likelihood, impact and weightages which are main inputs for Expected Value Method is not possible within the scope of Expected Value Method. So, fuzzy logic is integrated within Expected Value Method to map the interrelationship between likelihood, impact and weightages. It is very useful for better practical results in terms of practical applications for risk mitigations as rankings are not overlapped and there is wide range of risk severity quantitative values and concept suits to field experts as results are simulating with field conditions. The fuzziness in results of expected value method are eliminated by incorporating fuzzy logic.

Hence Fuzzy EVM method is better for defining risk severity ranking and for risk mitigations.

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**Annexure 1:** Risk Severity Classification

**Table 1:** Risk Severity Classification (For EVM)

| Sr. No. | SEVERITY | CLASSIFICATION |
|---|---|---|
| i | 0.000 – 0.010 | Very Low Risk |
| ii | 0.011 – 0.110 | Low Risk |
| iii | 0.111 – 0.150 | Medium Risk |
| iv | 0.151 – 0.200 | High Risk |
| v | 0.201 – 1.000 | Very High Risk |