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Assessment of Risks Associated with Elevated Metro Rail Projects by using Fuzzy Failure Mode a nd Effect Analysis

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Abstract

Objective: To identify the risk factors in metro projects through literature reviews and interviews and to assess identified risks using Fuzzy FMEA. **Method:** An under construction elevated metro viaduct is documented, and Fuzzy FMEA is used to assess risks identified through the study. **Findings:** The application of Fuzzy FMEA in elevated metro construction was demonstrated and conclusions were drawn from the findings of the study. It was identified that risks under physical and economic category are high and construction risk fall between low and medium post mitigation. **Novelty:** This study highlights the critical aspects of risks in elevated metro projects in India; also, it provides mitigation strategies to each of the independent variable to keep the risk and time under control.

Keywords: Risk management; Risk assessment; metro rail; Elevated metro rail; FMEA; Fuzzy FMEA

1 Introduction

According to the India census conducted in 2021, 35.39% of Indians live in urban areas. By 2050, it's expected to rise to 60%. In the last ten years, 15 metro rail projects have been started, 6 new metro projects are being built, and 11 cities have proposed metro projects in India to increase the availability of public transportation. As a form of public transportation, metro rail projects frequently experience problems like late completion and delays in their planning and execution in spite significance and need[(1)]. Line 2 of Jaipur Metro is delayed as approvals in predesign stage are pending from the state government side. The construction of underground section of metro rail phase 2 in Chennai is predicted to be delayed by minimum of 9 months due to delay in tendering process. Land acquisition challenges for ISBT metro depot in Patna forecasts schedule delay in completion of the project. Change of scope of work in metro service proposed between Ahmedabad and Gandhinagar cost a total of 9000 crore rupees escalation due to delay with an approximated per day delay cost of 40 lakh rupees. Mumbai Metro 3 underground was delayed by almost two years due to financial crunch if after procurement of about 60% of metro 3 project cost as loan from Japan International Cooperation Agency (JICA). The Kochi Metro phase II project is at hold from 2018 after Detailed Project Report approval which will cause schedule and cost escalations. Risks in construction phase are higher than design phase [2]. The complicated engineering geological context that metro development typically takes place in can lead to a number of risk events. By taking the appropriate mitigation measures during the design and planning phases, risks in a building project can be minimized or transferred from one partner to another Hence research-based risk analysis is required during the metro construction process to reduce and control risks [3–7]. Literature on possible risk and various analysis tools available will assist this paper [4]. Previous works cover underground and elevated metro projects [5], involve multiple aspects to assess namely time cost quality [6] and multiple risk categories [7]. Identifying major risk categories and in depth analysis of each category is not covered in the reference literature. Also, risk identification and analysis to metro rail project specific to schedule constraints is unavailable. The finding showed that risk assessment using fuzzy FMEA provides more accurate and corrective action prioritization is better performed than traditional FMEA. [8–10]. Similarly, the use of Fuzzy FMEA as a risk assessment tool is not established. This study aims to be case specific in listing and analysing the risks associated with elevated viaduct construction of metro projects and in application of the Fuzzy FMEA as risk analysis tool.

2 Methodology

As part of the initial study, the current predicted risks in elevated metro rail construction industry are explored through a structured questionnaire survey. According to Iarossi (2006), the questionnaire survey method is considered to be cost effective and time saving for achieving better results in shorter duration. Relative Importance Index (RII) method is used to rank the identified risk categories.

The research proceeds to a case specific field study on metro viaduct construction to collect primary data values for probability, impact, weightage and detection of the risk. The target population for the survey was Site engineers, Structural engineers, Construction managers, Safety mangers and Designers. Risks have many aspects and it is necessary to consider various perspectives to the same. Designers are aware of risks that can happen in preconstruction and redoes that can cause delays in construction phase. Whereas, a safety manager deals with risks in terms of labour safety, injuries and accidents that can occur. A site engineer has knowledge of day to day challenges whereas a structural engineer can elaborate on civil oriented risks that has occurred or might occur at site. A construction manager can give overall insight of risks at various levels from casting to delivery to execution. A total of 70 responses were collected from Chennai to support the study. Using these linguistic terms, the identified risks have been defined as low, medium, high, very high and critical according to their RPN and Fuzzy RPN values.

2.1 Case Study

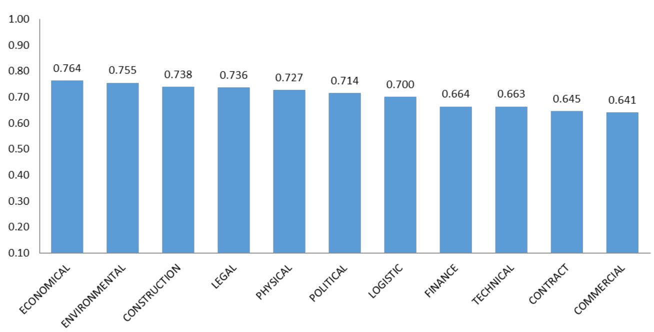

Fig 1. RII Values for Risk Categories

The values of RII of each category of risk are calculated and plotted in Figure 1. The mean from RII was identified to be 0.716. So considering categories above the mean value the top 5 categories of risk are Table 1 identified to be Economic, Environmental, Construction, Legal and Physical. In these categories Environmental and Legal category of risk are specific to the region of study whereas economic, construction and physical risks are general to metro projects in a region. Thus, Economical, Construction and Legal risk categories are considered for further assessment, while case specific mitigation strategies will be provided to environmental and legal risk categories. Risks associated with Economic, Construction and Physical categories with RII value above 0.716 are mentioned in the table below in Table 1.

Risks in a project will impact directly on one or more of the triple constraints namely Cost, Time and Quality. This paper focuses on risk in metro projects that have direct impact on time (schedule). Thus identified risk was further shortlisted to identify risks with direct impact on schedule of metro projects as shown in Table 1.

Table 1. Identified Risk Vs Risk Impact Category

Risk Identification		Risk Imapct Category		
S. No	**Risk Description**	**Cost**	**Schedule**	**Quality**
ECONOMICAL				
1	Change in supplier/contractor	•	•	•
2	Inflation or variation in material prices	•		
CONSTRUCTION				
1	Casting of pile	•	•	•
2	Pier cap	•	•	•
3	Segment storage	•	•	•
4	Segment erection		•	
5	Obligatory span	•	•	•
PHYSICAL				
1	Shortage of resources	•	•	•
2	Labour injuries		•	
3	Damage to equipment	•	•	

Elevated metro corridors risk increases with increase in height. Chennai metro phase II which is under construction is the tallest viaduct in India at 37 m high. Located at the Alandur junction this metro corridor is planned to cross over an existing Kathipara flyover (Asia's largest clover shape flyover) and completed Phase I corridor of Chennai Metro. Phase 2 route spanning across existing junction and metro line involves four twin piers cast *in situ*. The pier head is prefabricated and erected on the piers. The obligatory span is curvilinear and spans across these piers. Six twin piers with span ranging from 60-100 is considered for the study. The total length of viaduct between these piers is 413m. The proposed route is being constructed above a full time functioning flyover and two operational metro lines. Hence, *in situ* casting of balanced cantilever method of construction is chosen for the span.

Phase I of metro project above Kathipara flyover has an existing *in situ* cast balanced cantilever method of constructed span. The BCM segments obligatory span is straight. BCM construction technique has been implemented in Kochi; Kerala. The Kochi metro's structure includes a 90-meter bridge that is not supported by pillars and is built over a railroad track. It is a curved design. The 200 m-long structure has two 65 m-long concrete spans that balance out the 90 m-long span on either end.

In a survey questionnaire, many risk variables were written out in relation to the various identified major activities. In this part, an expert must express their judgement of the importance of the risk, the likelihood that it will occur, the seriousness of the behaviours, and the detection values. To achieve the purpose, questionnaire was produced in which survey participant will have to fill out the frequency of occurrence, severity level of the risk factor determined and detection in the questionnaire form. A set of population with experience varying from fresher's to more than 10 years of experience professionals from client, general consultants and contractors were chosen. About 42% of the responses are from professionals with expertise of more than 10 years in the field of metro construction and a cumulative of 78% of professionals is above 5 years of experience.

2.2 Data Analysis

In order to represent the Occurrence (O)j, the likelihood (Lij) of all risk sources for each activity j can be combined. The weightages (Wij) of the risk sources of the activities are multiplied with their respective likelihoods to obtain the O for the activity. The relationship of computing the O as a weighted average is given below:

$$Occurance\ Oj\ =\ \sum_{LijWij,} M\ i = 1\ for\ all\ j \quad (1)$$

The effect a risk has on an activity's time and cost can be used to describe its influence. This time and cost impact could be seen as the risk time and cost of the action. By taking into consideration the weighted average in accordance with the connection shown below, a calculation comparable to that of likelihood may be done to generate a single combined composite factor Severity (S) as per the relationship given below:

$$Severity\ Si\ = \sum_{IijWij,} M\ i = 1 \tag{2}$$

CIF (Severity) and CLF (Occurrence) were calculated for each attribute by using Equations (1) and (2) is tabulated in Table 2.

Table 2. Calculation of Severity and Occurrence

Risk Identification		Data Collection			Data Calculation	
S. No	**Risk Description**	**Weightage**	**Impact**	**Probability**	**Severity (CIF)**	**Occurrence (CLF)**
ECONOMIC						
1	Change in supplier/contract	0.970	0.62	0.60	0.600	0.579
CONSTRUCTION						
2	Casting of pile	0.772	0.57	0.46	0.439	0.357
3	Pier head	0.929	0.63	0.51	0.586	0.473
4	Segment casting	0.970	0.66	0.60	0.642	0.587
PHYSICAL						
5	Shortage of resources	0.960	0.70	0.67	0.669	0.641
6	Damage to equipment	0.912	0.56	0.45	0.508	0.414
7	Labour safety	0.912	0.56	0.47	0.508	0.425

The product of the factors severity (S), occurrence (O), and detection (D) yields the risk priority number (D). The higher the RPN, the greater the risk, according to FMEA. RPN value for identified risks is calculated as shown in Table 4.

2.3 By Using Fuzzy Failure Mode and Effect Analysis

One membership function had to be defined for all risk factors in order to transform every linguistic variable into fuzzy values. Triangular fuzzy numbers must be used to define the membership functions. In comparison to trapezoidal fuzzy, triangular fuzzy computation was rather straightforward. Based on the severity, likelihood of the risk, and likelihood of its discovery, the membership functions' values "Very Low ", "Low ", "Medium", "High", and "Very High" are defined. The linguistic scale's values were set in increments of 0.25 from 0 to 1.

Severity, occurrence, and identification of risk have values between 0 and 1. Both quantitative and qualitative descriptions of the dangers' levels of severity are required. For each of the seven key risk categories, the severity (S), occurrence (O), and detection (D) data collected from experts were used as inputs for the fuzzy technique using MATLAB software (Version R2014a). Software was used to develop five Membership functions and 125 rules. All 7 primary risk outputs are derived as fuzzy risk priority numbers (FRPN). In the Table 4, all values are tabulated.

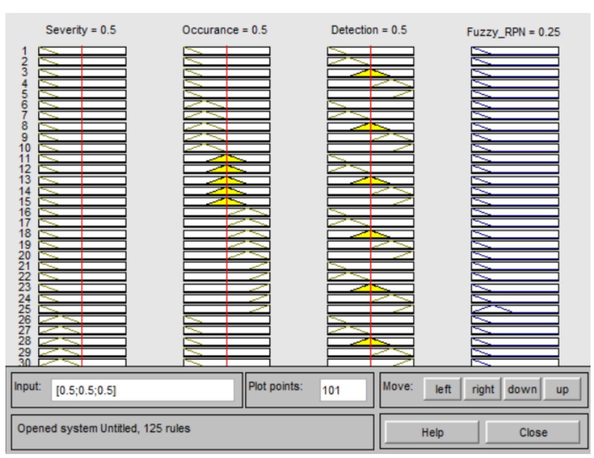

Fig 2. MATLAB Representation of FRPN for Risks

Table 3. Comparison of FMEA and Fuzzy FMEA for All 7 Risk Activities

Risk Category	Risk Description	Risk Priority Number			Risk Category	Risk Description	Fuzzy Risk Priority Number		
		Quantitative (SxOxD)	Qualitative	Rank			Quantitative (SxOxD)	Qualitative	Fuzzy FMEA Rank
C	Segment Casting	0.419	Critical	1	C	Segment Castin	0.540	Critical	1
P	Shortage of Resources	0.314	Very high	2	P	Shortage of Resources	0.456	Critical	2
E	Change in Supplier/Contract	0.275	High	3	E	Change in Supplier/Contract	0.408	Critical	3
C	Pier Head	0.212	High	4	P	Labour Safety	0.270	High	4
P	Labour Safety	0.195	Medium	5	C	Pier Head	0.250	High	5
P	Damage to Equipment	0.175	Medium	6	P	Damage to Equipment	0.247	High	6
C	Casting of Pile	0.139	Medium	7	C	Casting of Pile	0.221	High	7

Table 3 Ranks the RPN and Fuzzy RPN values for each of the seven identified risks. It is understood from the table that Segment casting which is a construction related activity falls under critical category of risk in both RPN and Fuzzy RPN and is ranked 1. Physical category of risk- Shortage of resources is high risk activity in RPN and Critical under fuzzy RPN and ranked 2. Economic related risk, change in supplier or contractor is ranked three with high risk under RPN and critical risk in fuzzy RPN. Construction risk pier head is ranked 4 in RPN and 5 in fuzzy RPN with high risk categorization. Physical risk- labor safety is ranked 5 with medium risk in RPN and ranked 4 in Fuzzy RPN with High risk categorization. Similarly, Damage to equipment and casting of pile which are physical and construction risk respectively are ranked 6 and 7 in RPN and Fuzzy RPN with medium and high categorization or risk.

3 Results and Discussion

The mitigation plan includes list of risk owns and risk actioners required to treat an identified risk. The major stakeholders in the metro rail project consider for case study includes CMRL- the client, AECON – the general consultant and Larsen and Toubro – the contractor. Strategies tabulated are upon interviews and questionnaire surveys conducted with professionals in the field of metro rail projects. Departments contacted include design team, civil team, structural consultants, procurement unit, quality assurance team, plant and machine, labour and contracts team, environmental assessment team, site engineers, safety department, erection team, casting and production team. Mitigations are listed to prevent or reduce the occurrence and severity of a risk. However constant monitoring and reporting during the execution phase is mandatory to ensure risks are under control.

4 Conclusion

This study identified variable factors and mitigation strategies to assess and mitigate risk by validating the use of fuzzy FMEA as a risk assessment technique in elevated metro constriction projects. The risk priority number (RPN) is a function of three parameters: the severity of the failure's effect, the chance of occurrence, and the ease of detection for each failure. A risk's probability of occurrence, impact, or chance is all decreased by a lower RPN. Adopting mitigation strategies RPN values can be considerably reduced critical to low. Similarly, Fuzzy RPN values can be reduced from critical to medium or high. It is understood that variable namely impact and probability of a risk must be reduced in order to reduce the RPN values.

Change in supplier or contract is identified to have higher changes or occurrence with significant impact on the construction activities. Casting of pile, Pier head and Segment casting can be brought under low to medium risk zones if mitigated properly. Shortage of resources, Labour safety and Damage to equipment fall under high risk zones after mitigation. Hence, it is important to monitor these activities regularly. The concept is open for additional mitigation strategies that can further reduce the probability and impact on construction and thereby reduce its respective Fuzzy RPN values.

RISK IDENTIFICATION						RESPONSE STRATERGY - IMPACT								RESPONSE STRATERGY - PROBABLITY								RISK EVALUATION							
S.NO	RISK TITLE	RISK CATEGORY	RISK TITLE	REASONS OF RISK	RISK OWNER	Values from data collection		STRATEGY	MITIGATION STRATEGY	RISK ACTIONEE	Predicted values after mitigation			Values from data collection		STRATEGY	MITIGATION STRATEGY	RISK ACTIONEE	Predicted values after mitigation			WEIGHTAGE	SEVERITY	OCCURANCE	DETECTION	RPN		FUZZY RPN	
						QUANT	QUAL				QUANT	QUANT (Avg)	QUAL	QUANT	QUAL				QUANT	QUANT (Avg)	QUAL					QUANT	QUAL	QUANT	QUAL
1	PHYSICAL	SHORTAGE OF RESOURCES	Shortage of skilled labour	- Migration workers	Contractor	0.697	HIGH	Reduce	- Backup team to be available in short notice - predict shortage earlier by holding meetings and understanding workers pulse	Contractor	0.4	0.4	LOW	0.668	HIGH	Avoid	- Increase pay - Make feel included in the team - Incentives and promotions to motivate - accommodations and benifits	Contractor	0.2	0.25	LOW	0.96	0.384	0.240	0.976	0.090	LOW	0.222	HIGH
			Shortage of material	- Improper procurement - Delay in placing order or transportation	Contractor			Reduce	- Work to be scheduled according to the availability of material - Reporting of material required for the next two days on daily basis is required - material manager to be appointed to document, report and raise claims for materials required and its usage	Contractor	0.4					Avoid	- Calculate proper lead time - Assess and keep a record of safety stock - Proper material handling and inspections - Material manager at site should be assigned	Contractor	0.2										
			Shortage of material for formwork	- Material sourced from Mumbai - Delay in manufactering and delivery of materials	Contractor			Reduce	- Alternate methodologies to be adopted - Access possible delays prior - Alternate suppliers to be kept as backup options - Source materials from multiple suppliers	Contractor	0.4					Avoid	- Schedule procurement and dates based on lead time. - Fine to be paid by the respective producer for any further delay than the proposed date of delivery - Strict contracts and penalties for overrun in terms of time or cost to be mentioned	Contractor	0.2										
			Shortage of power/diesel to operate	- increase in crude oil prices - fall of rupees	Contractor			Reduce	- go Electric as future of diesel is limited - Ceck for substitutes like hydrogen in place of fuel	Contractor	0.4					Reduce	- Access required quantity of fuel and form proper contacts and tie ups with supplier - Reduce depency on fuel as much as possible	Contractor	0.4										
2	CONSTRUCTION	SEGMENT CASTING	Segment casting not balanced on either side	- Error is calculation - human errors	Contractor			Avoid	- Supports to be provided if failure reported to prevent collapse - Obstruct traffic and movement below construction in case of failure - Secure labours safety - Strategies to solve structural issues must be kept in hand prior to casting	Contractor	0.6					Avoid	- Casting to be done simultaneously - Load calculation and volumes to be followed - Supervision by Site and structural engineer	Contractor	0.2										
			Fall of object from height	- Human error	Contractor			Avoid	- regularly inspect conditions of the safety net - Avoid intense works when traffic is at peak - Supervision throughout work required - inspection of tools and workers at height is mandatory	Contractor	0.4					Avoid	- proper training for handling equipment and materials - inductions and weekly safety meetings required - proper supervision - safety nets while working at height are mandatory - use lanyards to prevent tools from falling - Limit tools and materials used at heights - Keeps floor space clear of materials and waste - toe Boards and rails around the scaffolding	Contractor	0.2										
			Mould change according to segments	- Curavture in design	Contractor			Avoid	- Filling if gaps are noticed - Inspection for dimensions post-casting to understand deviations and corrections required before proceeding to next casting	Contractor	0.2					Avoid	- Moulds to be prepared and followed according to GFC drawings - Supervision and approval before casting required	Contractor	0.2										

Fig 3. Risk Treatment Strategies for Independent Variables

RISK IDENTIFICATION						RESPONSE STRATEGY - IMPACT								RESPONSE STRATEGY - PROBABLITY								RISK EVALUATION							
S. NO	RISK TITLE	RISK CATEGORY	RISK TITLE	REASONS OF RISK	RISK OWNER	Values from data collection QUANT	Values from data collection QUAL	STRATEGY	MITIGATION STRATEGY	RISK ACTIONEE	Predicted values after mitigation QUANT	Predicted values after mitigation QUANT (Avg)	Predicted values after mitigation QUAL	Values from data collection QUANT	Values from data collection QUAL	STRATEGY	MITIGATION STRATEGY	RISK ACTIONEE	Predicted values after mitigation QUANT	Predicted values after mitigation QUANT (Avg)	Predicted values after mitigation QUAL	WEIGHTAGE	SEVERITY	OCCURANCE	DETECTION	RPN QUANT	RPN QUAL	FUZZY RPN QUANT	FUZZY RPN QUAL
			Form traveler erection and assembly related falls	- Human error	Contractor	0.66	HIGH	Avoid	- Floor area to be kept clear of labors and public - PPE mandatory -	Contractor	0.4	0.429	MED	0.6	HIGH	Avoid	- Erection instructions to be provided by the erection head only and coordinated by the crane operators according - well trained persons to be appointed for the tasks -proper training for handling equipment - inductions and weekly safety meetings required - proper supervision - safety nets while working at height are mandatory - Keep floor space clear while erection is happening - Restrict traffic	Contractor	0.2	0.257	LOW	0.97	0.416	0.249	0.832	0.086	LOW	0.191	MED
			Difficult of Movement of form traveler in curves	- Minimal experience in BCM	Contractor			Avoid	- Make schedule accessing possible delays - Alternate labour team to complete the task as backup - supervision throughout the task	Contractor	0.2					Avoid	- Understanding operation of form travellor - Hire experienced labour for thr task - proper induction to the project and task - clear milestone plan to be established	Contractor	0.2										
			Curvature radius not maintained	- Work not well supervised - Inspections not done properly	Contractor			Reduce	- try to allign while casting centre stitch	Contractor	0.6					Avoid	- Inspect before and after every segment casting	Contractor	0.4										
			Level not matching at centre stitch	- Casting not inspected - Pre camper effect due to excess stressing	Contractor			Reduce	- Add loads like sand bags at the edges of the cantilever to create a counter pressure and align the the ends	Contractor	0.6					Avoid	- required stressing values to be mentioned in method statements - supervision to be done to inspect the levels of stressing after each segment casting	Contractor	0.4										
3	ECONOMIC	CHANGE IN SUPPLIER/CONTRACT	Change in supplier for material	- Delay in supply - Ineffiency in supply - Increase in rates of materials and transportation	Contractor	0.62	HIGH	Reduce	- impact on construction can be reduced if predicted earlier and backup suppliers are ready available	Contractor	0.2	0.3	LOW	0.6	HIGH	Reduce	- Supplier changes are to occur as and when required - Preferable to previously worked suppliers - Not to rely on a Single supplier - Backup options before start of construction process required	Contractor	0.4	0.4	LOW	0.97	0.291	0.388	0.976	0.110	MED	0.224	HIGH
			Change is contracts for labour	- Inefficeincy - inconsistent - Migration of labours - Strikes and otehr issues	Contractor			Reduce	- Prompt induction - Quick resume of work - Ensure these labours stay till completion of work	Contractor	0.4					Reduce	- If the team is found efficient to work increase payments and add incentives to make them work - If labours need to be changed, then induction must be done quickly and promptly to accomodate the new labours and commence work as soon as possible - reduce the time between the change of old labour to new labours as much as possible	Contractor	0.4										
4	CONSTRUCTION	PIER HEAD	Fall of object from height Falls related to erection of fabrication	- Human error	Contractor	0.63	HIGH	Avoid	- regularly inspect conditions of the safety net - Avoid intense works when traffic is at peak - Supervision throughout work required - inspection of tools and workers at height is mandatory	Contractor	0.4	0.4	LOW	0.51	MED	Avoid	- proper training for handling equipment and materials - inductions and weekly safety meetings required - proper supervision - safety nets while working at height are mandatory - use lanyards to prevent tools from falling - Limit tools and materials used at heights - Keeps floor space clear of materials and waste - toe Boards and rails around the scaffolding	Contractor	0.2	0.2	VERY LOW	0.929	0.372	0.186	0.764	0.053	LOW	0.128	MED

Fig 4. Risk Treatment Strategies for Independent Variables

RISK IDENTIFICATION						RESPONSE STRATERGY - IMPACT								RESPONSE STRATERGY - PROBABLITY								RISK EVALUATION							
S.NO	RISK TITLE	RISK CATEGORY	RISK TITLE	REASONS OF RISK	RISK OWNER	Values from data collection QUANT	Values from data collection QUAL	STRATEGY	MITIGATION STRATEGY	RISK ACTIONEE	Predicted values after mitigation QUANT	Predicted values after mitigation QUANT (Avg)	Predicted values after mitigation QUAL	Values from data collection QUANT	Values from data collection QUAL	STRATEGY	MITIGATION STRATEGY	RISK ACTIONEE	Predicted values after mitigation QUANT	Predicted values after mitigation QUANT (Avg)	Predicted values after mitigation QUAL	WEIGHTAGE	SEVERITY	OCCURANCE	DETECTION	RPN QUANT	RPN QUAL	FUZZY RPN QUANT	FUZZY RPN QUAL
5	PHYSICAL	LABOUR SAFETY	Working at height safety related risks	- Fall of labour - Injuries	Contractor	0.56	MED	Reduce	- Medical facilities to be provided - replace labour to finish work - Make other worker aware and reduce conflicts	Contractor	0.4	0.4	LOW	0.47	MED	Avoid	- Ensure proper work platform for height provided - Tag systems to be folowed - Full body safety should be followed - Barricade the work area at height - height work permit to be uised - Unauthorized entry should be prohibited	Contractor	0.2	0.2	VERY LOW	0.912	0.365	0.182	0.904	0.060	LOW	0.212	HIGH
			Labour injuries on site	- slip trip or fall	Contractor																								
6	PHYSICAL	DAMAGE TO EQUIPMENT	Breakdown of equipments (rigs)	- Mishandling of equipment - Over usage - not maintained well	Contractor	0.56	MED	Reduce	- try and reduce downtime - In-house mechanics to inspect machines - Spare machine if budget allows	Contractor	0.4	0.4	LOW	0.45	MED	Reduce	- inspect before usage everyday - Service and maintain equipment - Equipment and machinery to be used by trained labours	Contractor	0.2	0.2	VERY LOW	0.912	0.365	0.182	0.832	0.055	LOW	0.201	HIGH
7	CONSTRUCTION	CASTING OF PILE	Identification of utilities not mentioned in DPR	- DPR not dealt in detail	Contractor	0.57	MED	Reduce	- Utilities team should divert the line as soon as possible - Or utilities contract should be provided to the same contractor - Budget and contract must be approved at the earliest - The number of days within which the issue will be solved should be mentioned s a clause in the contract before commencement and allocation of contractor initially	Client	0.4	0.267	LOW	0.46	MED	Reduce	- Utility and geotechnical tests must be done within the region on pile and pile cap and not in proximity to it - In terms of older roads deeper testing is mandatory to identify utilities and Geotechnical issues	Client	0.2	0.15	VERY LOW	0.772	0.206	0.116	0.883	0.021	LOW	0.093	LOW
			Geotechnical challenges not predicted in DPR																										
			Change in shoring method due to geotechnical challenges	- On site challenges not mentioned in DPR	Contractor			Avoid	- Additional cost and change in schedule must be accomodated by the client	Client	0.4					Avoid	- DPR should be in detail - Cause for an unidentified geotechnical issue with the number of days of reply back must be mentioned	Client	0.2										
			Collapse of bore hole during boring	- Soil not stable	Contractor			Avoid	- rework	Contractor	0.2					Avoid	- Identify soil nature before bore hole - Iron pipe to be installed to prevent soil collapse	Contractor	0.2										
			Bentonite tank lifting and shifting related risk by using 45 Ton mobile crane related falls	- Improper lifting - Crane operator not trained	Contractor			Avoid	- ensure labour safety on site	Contractor	0.2					Avoid	- Crane operator must be trained - Crane must be inspected before use - Instructions to crane operator to be given by the trained person in charge	Contractor	0.1										
			Tremie pipe, liner punching and rebar cage lifting and shifting related falls	- improper lifting and erection into pile holes	Contractor			Avoid		Contractor	0.2					Avoid		Contractor	0.1										
			Disposable scheme during piling is not in schedule	- Method statement not in detail	Contractor			Avoid	- Recommend, request, and sort out the issue	Client	0.2					Avoid	- Check before the commencement of work	Client	0.1										

Fig 5. Risk Treatment Strategies for Independent Variables

Table 4. Comparison of FMEA and Fuzzy FMEA for All 7 Risk Activities Before and After Mitigation

Risk category	Risk description	Risk assessment							
		RPN				Fuzzy RPN			
		Value from Data Analysis		Predicted values after Mitigation		Value from Data Analysis		Predicted values after Mitigation	
		Quan.	Qual.	Quan.	Qual.	Quan.	Qual.	Quan.	Qual.
Physical	Shortage of resources	0.419	Critical	0.090	Low	0.54	Critical	0.222	High
Construction	Segment casting	0.314	Very high	0.086	Low	0.456	Critical	0.191	Medium
Economic	Change in supplier/contract	0.275	High	0.110	Medium	0.408	Critical	0.224	High
Construction	Pier head	0.212	High	0.053	Low	0.27	High	0.128	Medium
Physical	Labour safety	0.195	Medium	0.06	Low	0.25	High	0.212	High
Physical	Damage to equipment	0.175	Medium	0.055	Low	0.247	High	0.201	High
Construction	Casting of pile	0.139	Medium	0.021	Low	0.221	High	0.093	Low

Risk analysis is a critical step in risk management because it allows practitioners to assess risks that have an impact on the cost, quality, safety, and timeline of a project. This study is limited to identification and assesses risks in terms of time. This paper focuses on schedule risks that cause delay in construction of elevated metro rail projects. Though the upcoming metro corridor chosen for assessment of risk is connected to an existing station, the selected area for study has no station within the stretch. Hence, this paper is limited to risks associated with metro viaduct construction. This paper will cover economic, environmental, construction, legal and physical risks associated with elevated metro projects and risks associated with political, logistic, financial, technical, contractual and commercial are not covered.

The future scope of this research activity includes the development of risk analysis models using the fuzzy Analytical Hierarchy Process (AHP) and fuzzy Interpretative Structural Modelling (ISM). As the principle is generic, identical risk analysis models can be constructed for any building project.

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