Risk Assessment of Pune Metro Underground Construction Using Risk Matrix and Expected Monitory Value

Shubhangi S. Wagh and Sandeep Potnis

Abstract Many complexities can be observed in the construction of tunnels for Pune metro (the second-largest city in the state of Maharashtra, India). It inherently involves many risky activities like excavation and lining, transportation of material, scaling and mucking, ventilation, cutter head intervention of tunnel boring machine (TBM) in compressed as well as in open mode, handling of tunnel machinery, working in narrow space, overloading of the crane, temporary segment dismantling, etc. Although tunneling for metro rail is risky, the risk involved is more in the longer tunnels. To save valuable resources and winning the trust of the client, risk assessment for each activity during tunnel construction is crucial. The expository literature review indicates that very few studies are available on risk assessment of each activity of tunnel construction in India using TBM. This study presents a case study on risk assessment of underground construction for the Pune metro. The work provides an insight into risk which occurs during the construction and describes general consideration for the uncertainties during execution. The paper provides the qualification and quantification for the risks in metro tunnel using risk matrix and expected monitory value (EMV) analysis. The risk matrix is the most effective tool for risk assessment and qualitative risk analysis. And EMV is succeeded using recommendations accessible in the literature of domain of risk management. Though it is a straightforward method, it is a productive application for the quantification to accomplish the goals of the metro tunnel project in terms of controlling the time delay and cost overrun as well. After the qualification of the risk process, quantitative assessment can be done for the further elected majors to choose the suitable reaction schemes. To manage the risk-associated cases efficiently. TBM data has been taken into account for risk assessment.

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1 Introduction

Pune metro rail project contract underground construction (UGC)-1 comprised the construction of twin-bored tunnels, ramp, and cut and cover tunnels, cross passages, and two underground stations. The total length of TBM tunneling for Pune metro underground construction is approximately 4.73 km including both tunnels. As the compacted basalt is present in the soil strata of the Pune city, the earth pressure balance (EPB) type of tunnel boring machine having diameter of 6.61 M is used for the construction of underground metro twin tunnel. According to the International Association of Engineering Insurers (IAEI), a financial loss of higher than 50 million euros was experienced in the worlds' 18 biggest tunneling projects from 1994 to 2005 because of underground construction misfortunes (Bluckert et al. 2006). Due to limited prior knowledge of geotechnical ambiguity, there is a provocation of sustainable safety throughout the complete tunneling project with no delays or no cost overrun. The risks are frequently attached to some type of recommendation. Tunneling works to manipulate risk for all parties which are not directly involved in the project. Because of the intrinsic unpredictability of ground (Subsoil) and the presence of appreciable groundwater, there may be remarkable cost overhead and time overrun risks along with some environmental risks. Along with these due to spectacular underpass collapses and other catastrophes recently, there is a probability of huge no. of misfortunes at the time of tunneling work. Project risk is the unresolved matter or circumstances that if it occurs, have a positive or negative impact on project goals. The successive indicators of the construction management systems are including finalizing the project with cost features and time features, within the decided cost and time and also within the required quality, safety, and environmental criteria. Accurate estimation and schedule must be categorizing in contemplation of intersecting the overall cost and time boundaries of the project. There are many circumstances where there could be a hindrance in activities, whether they are within a limit to the critical path or not, which results in delay in the overall project period. These time overruns will accordingly have an adverse effect on the quality, cost, and also on the safety of the project.

2 Literature Review

Risk is the maneuver of measurement of likelihood, intensity, and manifestation to all hazards for an activity. There are always the chances of failure in the execution of planned activities in infrastructure projects. So, the project risks affect the chances of occurrences of unknowing of the technical, scheduler, and budgetary outcomes.

One researcher named Williams and Dorofee [1] had worked on growing methods by which risk management can be put into the practice. The observed risks should be divided into different categories, to facilitate the decision making about risk response strategies. Several researchers like, Johnson and Rood, and Ashley [2, 3], have classified risks on the basis of various parameters. According to Roetzheim [4], the probability of recognized risks can have a value with a range between 0 and 1 which indicates 0 or 100% chance of happening. However, on the other hand, the priority connected with every risk origin from some work package/ activity is always equal to 1. Repetition of events and weight is always proportional to the cumulative likelihood factor (CLF). A number of variations of risk management approach have been proposed by different authors and researchers. According to Jamal and Kaith [5], risk management can be divided into four activities: risk identification, risk Analysis and evaluation, response management, and system administration. Royer [6] has pointed out that "unmanaged or unmitigated risks are one of the primary causes of project failure"; hence, risk management is the crucial step of project management. Hillson [7] has shown that for clear understanding and management of the risks, the risk management is an activity aimed at identification and assessment of the risks.

Lack of effective risk management can lead to delay of projects, budget over run, and missing the critical performance targets. Soren [8] also pointed out that there can be any combinations of these troubles. He has given guidelines for tunneling risk management at pre-construction, construction, and operation phase of the tunnel project. The most important step in the process of risk management is the identification of risk. All the potential hazards, which may adversely affect the project goals, are shortlisted in this step. According to Ahmad, Berman, and Sataporn [9], various methods such as brainstorming, checklist, cause–effect diagram, tree diagram, hazard and operability study, fault tree, decision tree, failure mode and effect analysis, Delphi technique and interviews can be implemented for identification of major risks. Akintoye [10] has concluded that, in case of large construction projects such as bridges and tunnels, risk management remains prominent feature of the project management to minimize the uncertainties and surprises.

Sharma [11] worked on general and specific requirements for safety during the construction of road tunnels by giving remedial measures for the risks and identified the gaps for the improvement in current field practice in India. Also, Marekar et al. [12] worked on the method of risk measurement of project risk, based on the risk matrix method. Hanna [13] worked on the effective implementation of accepted matrix beliefs to reduce the limitations of risk matrix and improve performance by risk analysis within the educated company. In spite of the restriction, the study identifies the risk matrix to be an applicable tool for qualitative risk assessment. According to Haytham [14], the risks are to identify the risks and developed strategies to reduce or avoid negative risks and on the other hand to catch opportunities. He focuses on the qualitative assessment of TBM tunneling project.

Limao et al. [15] work on a multilayer data combination frame which is suggested for the safety risk approach with both hard as well as soft data considerable. The result specifies that the progress procedure is effective for integrating many source instructions to accomplish a more precise outcome for the safety risk approach. As

Roopdarshan [16] said that the expected monitory value is a straightforward but constructive risk measurement quantitatively and will help to support the business objectives of the RMC crop in terms of RMC production and supply. Therefore, in the literature, it can be concluded that (i) a risk is a component which cannot be eliminated, and suitable risks mitigation measures are to be suggested which would enable to reduce identified project risks. (ii) EMV is the most widely used method, as this technique does not require any costly resources, only the experts' opinion. (iii) This technique gives the average outcome of all uncertain events. (iv) A proper risk mitigation plan is developing for the identified risks, and it ensures better and smooth achievement of project goals within specified time, cost, and quality parameter.

Objectives of this work are decided as follows:

1. To find and study the parameters that affect cost overruns and planning as a whole.
2. To increase the no. of distribution charts of occurrence, cost–effect, and time effect (risk matrix).
3. To quantify the impact of risk on the cost and time of the project using expected monitory value (EMV) tool.

3 Research Methodology

The risk assessment is a systematic process which consist of identifying, analyzing, and responding to the risks. The main purpose of the assessment incorporates maximizing of probability and of good events with reducing the probability of unfavorable events to the project. In the assessment process, there are mainly time and cost, both are the most important parameters to categorize the risk. As per the procedure, the first step is a literature review, and on site observations were used to identify the risk factors, and then discussion with an industry expert regarding the risk factors is identified and categorizing those identified risks based on technical, contractual, political, and environmental and precautionary. The risk assessment is the second stage in which there is a focus mainly on risk scenario, which is considered. Under this process, the risk matrix is used for qualitative risk assessment by giving a rating to every risk scenario by using a 5-point Likert scale and prioritizing the risk as per risk rating. The next stage is to perform a quantitative risk assessment by using the expected monitory value under which critical risk factors are decided. While the last and important stage is formulating the risk response strategy from this, estimated duration and cost with risk response plans are formulated for the consideration of ongoing tunnel construction projects. The format of this paper considers risk as a future event with a negative event in time and cost for organization executing metro tunneling project and for which feasible results can be forecasted on the basis of probability. Approach for this work consists of three levels

1. Risk identification, classification, and categorization
2. Risk qualification and prioritization

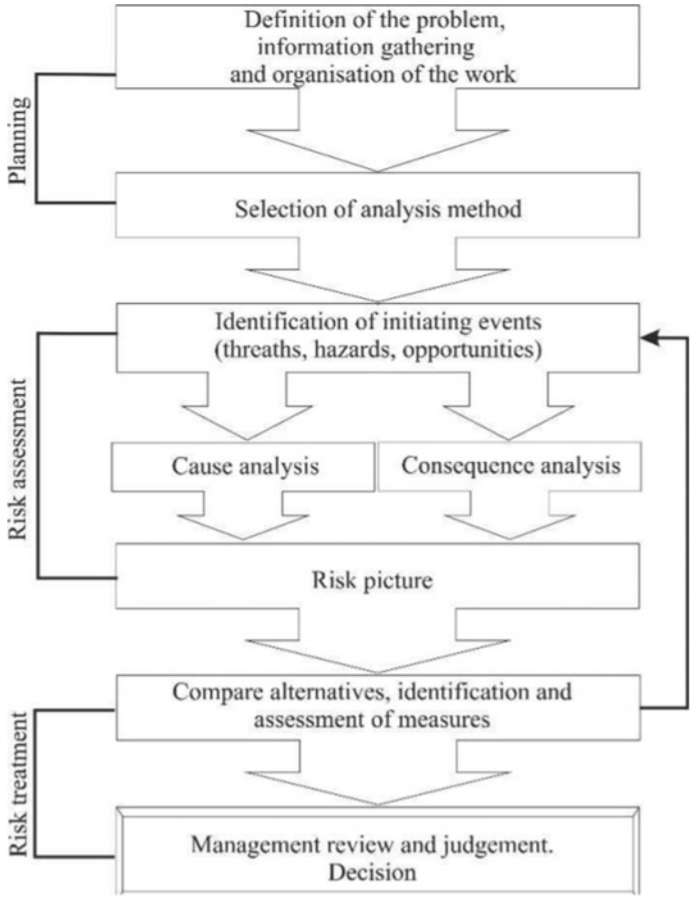


Fig. 1 Main step of risk analysis process

3. Risk quantification (Fig. 1).

3.1 Risk Matrix

A risk matrix is a table with categories of the probability of occurrence or frequency on an axis and the amount of impact on a second axis. Risk matrices are used mostly in risk management. Within the matriculation risk, there is a combination of probability, and the results are often met with a limited number of species considering different colors. These colors are usually green, yellow, and red representing low, medium, and large hazards, respectively. This can be obtained from the risk score given by the merger of probability and consequences. According to Davidson and his partner, risk matriculation can be used to measure risk levels. The possibilities for the emergence

Table 1 Scale of likelihood and consequences

Value scale	Assessment of likelihood (P)	Assessment of impact (C)
1	Very unlikely	First aid/very minor
2	Unlikely	Medical treatment/low effect
3	Possible	Lost time/rest injury/medium
4	Likely	Fatality/high effect
5	Very likely	Multiple fatality/extreme high effect

Source Marekar et al. [12]

Table 2 Impact matrix

Rank	Schedule	Cost	Safety
Very high	> 1 Month	> $1000,000	Multiple fatality
High	> 1 week	< $1000,000	Single fatality
Moderate	> 1 day	< $100,000	Lost time/rest injury/medium
Low	< = 1 day	< $10,000	Medical treatment/low effect
Very low	< 8 h	< $1000	First aid/very minor

Source Marekar et al. [12]

and other approaches are also explored in different categories and identified in the risk matrix. The scale of likelihood, consequences, and impact of these risks on the project was mentioned in Tables 1 and 2, etc. The result is in the way of measuring points from one to five as shown in Table 3. The number of occurrences and the risk factors are changed from a scale of one to five to zero to one using the following formula (Figs. 2, 3, 4 and Tables 4, 5).

$$\text{Required score} = (\text{Responded score} * 0.2) \quad (1)$$

Source: Marekar et al. [12].

3.2 Risk Prioritization

Risk prioritization is done to prioritize risk so that risks posed to stimulate project objectives are selected for distribution. Because of this, it is possible for the results

Table 3 Questioner responses

S. No.	Identified risks	Response on scale 1–5		
		P	C/S	R
1	Movement of trailer truck	4	5	H
2	Hit or crushed by moving trailer	4	5	H
3	Failure of crane while lifting loads	4	5	H
4	Improper set up /stabilization	4	5	H
5	Slings breakage/ failure	3	3	M
6	Over loading of crane	3	3	M
7	Collision of lifting equipment's / load	4	5	H
8	Falling of load	4	5	H
9	Lack of oxygen/improper lighting	2	2	L
10	Inadequate ventilation	2	2	L
11	Fire explosion and flying particles	3	5	M
12	Electrocution	4	4	H
13	Breakage of lifting pin	4	2	M
14	Water leakage from segment	1	1	L
15	Derailing of locomotive during in and out of the tunnel	4	4	H
16	Fall or tilting of segment	4	4	H
17	Cutter head intervention of both open and compressed mode	4	4	H
18	High underground water pressure	3	3	M
19	Improper grouting at the time of segment erection	3	3	M
20	Building settlement due to TBM vibration	3	4	M
21	Falling of load	4	5	H
22	Ring erection – crushing/ fractured/drop segment	4	5	H
23	Unsafe handling of chemical	4	3	M
24	Control of construction waste	4	5	H

to be set for individual risks based on the matrix used (probability–consequences matrix) (Fig. 5).

3.3 *Expected Monitory Value*

At this stage of the proposed approach, risks that could cause significant costs and overtime will be determined to get an idea of the overall risk of the project in terms of operating time and costs on site. The proposed format for this purpose is proposed, which will be used to collect data related to the probability and consequences of the "significant" as well as the high risk of exposure to time and cost. The likelihood of the identified risks can have a value ranging from 0 to 1, which indicates a 0–100% chance of occurrence (Figs. 6, 7 and Table 6).

A standard equation for EMV is shown below.

$$\text{EMV} = \text{Consequences of an single risk X Probability of this consequences} \quad (2)$$

Source: Roopdarshan et al. [16].

SEVERITY/ IMPACT CRITERIA		PROBABILITY FOR POTENTIAL INCIDENT SEVERITY/ IMPACT				
Personnel	**Operations** Asset damage Downtime	**(1) Very Unlikely**	**(2) Unlikely**	**(3)Possible** but unusual	**(4) Likely** not surprising	**(5) Very Likely** no doubt
(1) First Aid	Slight (<$1,000) 8 hours	1	2	3	4	5
(2) Medical Treatment	Minor (<$10,000) <= 1 day	2	4	6	8	10
(3) Lost Time/ Rest. Injury	Medium (<$100,000) > 1 day	3	6	9	12	15
(4) Single Fatality	Major (<$1,000,000) > 1 week	4	8	12	16	20
(5) Multiple Fatality	Extensive (>$1,000,000) > 1 month	5	10	15	20	25

1 – 6	**Low Risk**	Personnel with competency and skills to perform the job have the authority to proceed after verbally discussing the job requirements with anyone performing the work with them. May be acceptable; however, review task to see if risk can be reduced further.
7 – 15	**Medium Risk**	Job shall only proceed with appropriate authorization after consultation with HS&E personnel and assessment team. Where possible, the job shall be redefined to take account of the hazards involved or the risk shall be reduced further prior starting the job (TRA Section 4, RISK IDENTIFICATION, ASSESSMENT AND CONTROL).
16 – 25	**High Risk**	The job must not proceed until it has been redefined or further control measures put in place to reduce risk. The controls shall be re-assessed for adequacy prior to starting the job.

Fig. 2 Risk matrix use for qualitative risk assessment

Fig. 3 Strategies for negative risks. *Source* Mohamed et al. [17]

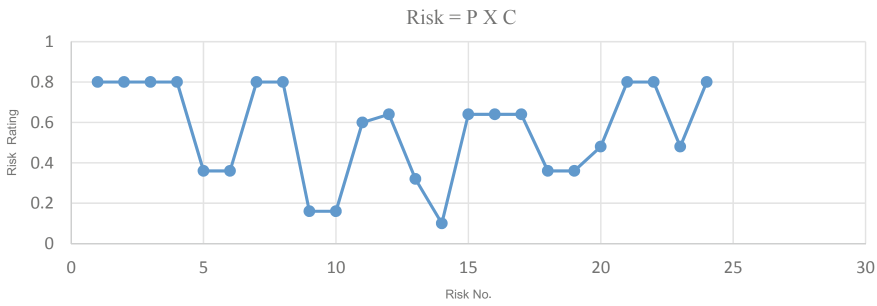


Fig. 4 Risk rating given by industrial experts

Table 4 Calculation of risk impact and occurrences

S. No.	P		C		Risk = $P \times C$
	Responded score	Score (P)	Responded score	Score (C)	
1	4	0.8	5	1.0	0.8
2	4	0.8	5	1.0	0.8
3	4	0.8	5	1.0	0.8
4	4	0.8	5	1.0	0.8
5	3	0.6	3	0.6	0.36
6	3	0.6	3	0.6	0.36
7	4	0.8	5	1.0	0.8
8	4	0.8	5	1.0	0.8
9	2	0.4	2	0.4	0.16
10	2	0.4	2	0.4	0.16
11	3	0.6	5	1.0	0.6
12	4	0.8	4	0.8	0.64
13	4	0.8	2	0.4	0.32
14	1	0.1	1	0.1	0.1
15	4	0.8	4	0.8	0.64
16	4	0.8	4	0.8	0.64
17	4	0.8	4	0.8	0.64
18	3	0.6	3	0.6	0.36
19	3	0.6	3	0.6	0.36
20	3	0.6	4	0.8	0.48
21	4	0.8	5	1.0	0.8
22	4	0.8	5	1.0	0.8
23	4	0.8	3	0.6	0.48
24	4	0.8	5	1.0	0.8

Fig. 5 Risk prioritization

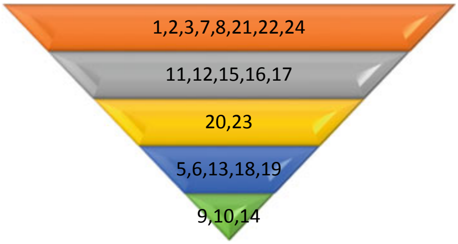


Fig. 6 Expected monitory value (time) h

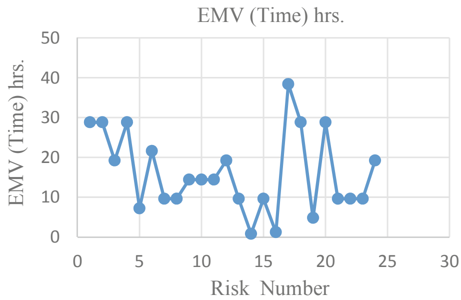
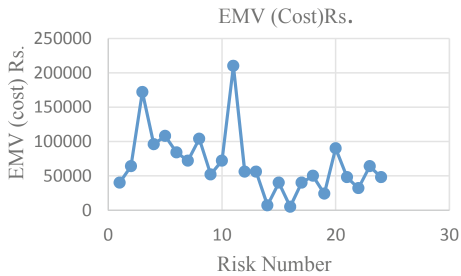


Fig. 7 Expected monitory value (cost) INR



EMV value is for threat expressed as negative values and for opportunity as positive value.

4 Results and Discussion

Risk analysis/evaluation was performed by using the risk matrix and EMV based on the identified risk scenarios. Table 3 presents the identified risk responses on a scale of 1–5 (Likert scale) given by industrial experts. In the category of tunnel construction-related works, the risk events, such as building condition survey, cutter head intervention, falling or tilting of the segment, ring erection, high underground water pressure, and improper grouting, were the main causes of time delay and cost

Table 5 Risk prioritization

Priority	Risk no.
First	1, 2, 3, 7, 8, 21, 22, 24
Second	11, 12, 15, 16, 17
Third	20, 23
Fourth	5, 6, 13, 18, 19
Fifth	9, 10, 14

overrun. Risk prioritization is to be done using risk rating given by industrial experts as shown in Fig. 4. As per risk prioritization movement of the trailer truck, hit or crushed by moving trailer, failure of the crane while lifting loads, ring erection, and control of construction waste were the critical risk scenarios. Due to these risks, time may increase up to 134.4 h. and cost may increase up to INR. 580,000; hence, it is necessary to mitigate first prioritize risks initially. Similarly, mitigate all prioritize risks sequentially, so that cost and time of the project may not increase. Table 5 summarizes all the categories of a tunnel construction project. As shown in the table, it is found that the total risk amount of INR. 1,634,000/- and time delayed for these risks is 386 h of the total project duration.

5 Conclusion

Based on the above results, it can be concluded that risk can be measured using the risk model and the priority model. This will be with caution in order to monitor and reduce the risk in infrastructure project. All projects should be managed to catch their objectives. The scope of risk management is not be restricted to planning stage only, but it should go through execution phase. Tunnels constructions are complex and risky projects which involve management of several risks. In this paper, it is shown that risks at the stage of the execution of project are the prime cause of project delay, cost overrun, and safety hazard. These risks can be controlled by implementing risk remedies. This paper presents the risk qualification and quantification perspective for TBM metro tunneling. The information is collected from tunneling site observations and consultation with a team of engineers working on the TBM project in Pune in India. The answer to the question of each TBM tunneling activity was developed as a result of this study. Consistent measurement, probability, and outcomes were also collected in the same risk assessment groups that had a significant impact on the goal of the project. The risk assessment concept proposed in this paper, using EMV, is a more accurate and productive tool for measuring risk in terms of time and cost. This approach can be used satisfactorily for decision making at the initial point of each TBM tunneling project. It facilitates the identification of high-risk areas that need to be managed and monitored to achieve project objectives in terms of cost and time. This idea can be made acceptable by including a computer decision support system, as long as the relevant information is available. It is shown that if the risks

Table 6 Expected monitory value

Risk No.	Threat (T)/opportunity (O)	Probability (*L*)	Impact on time (h)	EMV (time) h	Impact on cost	EMV (cost) Rs.
1	T	0.8	36	28.8	50,000	40,000
2	T	0.8	36	28.8	80,000	64,000
3	T	0.8	24	19.2	215,000	172,000
4	T	0.8	36	28.8	120,000	96,000
5	T	0.6	12	7.2	180,000	108,000
6	T	0.6	36	21.6	140,000	84,000
7	T	0.8	12	9.6	90,000	72,000
8	T	0.8	12	9.6	130,000	104,000
9	T	0.4	36	14.4	130,000	52,000
10	T	0.4	36	14.4	180,000	72,000
11	T	0.6	24	14.4	350,000	210,000
12	T	0.8	24	19.2	70,000	56,000
13	T	0.8	12	9.6	70,000	56,000
14	T	0.1	8	0.8	70,000	7000
15	T	0.8	12	9.6	50,000	40,000
16	T	0.1	12	1.2	50,000	5000
17	T	0.8	48	38.4	80,000	40,000
18	T	0.6	48	28.8	150,000	50,000
19	T	0.6	8	4.8	40,000	24,000
20	T	0.6	48	28.8	150,000	90,000
21	T	0.8	12	9.6	60,000	48,000
22	T	0.8	12	9.6	40,000	32,000
23	T	0.8	12	9.6	80,000	64,000
24	T	0.8	24	19.2	60,000	48,000

are identified and controlled using this approach. It leads to reduction in excessive costs and completion period of the project.

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