A Framework of Project Risk Management for the Underground Corridor Construction of Metro Rail

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Abstract

In this paper, we discuss a method of measurement of project risk, based on the expected value method (EVM). Project risk management primarily comprises cost and schedule uncertainties and risks associated with each activity of the project network. We have identified the major risk sources and quantified the risks in terms of likelihood, impact and severity in a complex infrastructure project for the construction of an underground corridor for metro railways. A case study of the underground metro corridor in the capital city of an emerging economic nation of South Asia has been considered for this research work. The methodology for this work was the response from the experts associated and involved in this and other similar projects in metro rail. The risk analysis for the determination of risk cost, risk time, expected cost and expected time of the project has been carried out by the expected value method. Based on this study we find that the project cost overrun and time overrun can be about 22.5 % and 23.4 % respectively, if we use the expected value method.

Keywords: Project risk management, Underground corridor, Metro rail, Expected value method

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1. Introduction

Risk management is an essential and integral part of project management in major construction projects. For an infrastructure project, risk management can be carried out effectively by investigating and identifying the sources of risks associated with each activity of the project. These risks can be assessed or measured in terms of likelihood and impact.

The major activities in underground corridor construction consist of feasibility studies, design, traffic diversion, utility diversion, survey works, shoulder piling and king piling works, timber lagging works, soil and rock excavation, construction decks, steel struts, rock anchors, sub-floor drainage, waterproofing, permanent structure works, mechanical and electrical installations, backfilling and restoration works. We have developed a questionnaire survey and personally interviewed experts from the underground corridor project. In this process, we have identified the risks at various phases of the project starting from the feasibility phase to the completion of the project. Then we have used the expected value method (EVM) to compute the effect of risky sources in terms of their impact and severity and also the overall effect on the project time and cost.

This paper is organized as follows. In section two, we discuss the review of related literature. In section three, we narrate the case study. In section four we discuss the methodology, which is based on the work of Roetzheim (1988) and Nicholas (2007). In section five we analyze the case by applying the EVM model to the underground metro construction project. We have also demonstrated the application of the Monte Carlo simulation on the risk management methodology to predict the expected time and cost of the project. Finally, in section six we discuss the conclusion and scope for future research.

2. Literature survey

Risk can be defined as a measure of the probability, severity and exposure to all hazards for an activity (Jannadi and Almishari, 2003). For an infrastructure project there is always a chance that things will not turn out exactly as planned. Thus project risk pertains to the probability of uncertainties of the technical, schedule and cost outcomes.

Williams, Walker and Dorofee (1997) worked on developing methods by which risk management could be put into practice. Their methods were based on software intensive programs (SEI) along with which specific road maps were designed. These could guide and help identify various risk management methods which could be easily put into practice.

Complex projects like the construction of an underground corridor for metro rail operations involve risks in all the phases of the project starting from the feasibility phase to the operational phase. These risks have a direct impact on the project schedule, cost and performance. Reilly (2005), Reilly and Brown (2004), Sinfield and Einstein (1998) carried out their research on underground tunnel projects. Reilly and Brown (2004) state that infrastructure underground projects are inherently complex projects with many variables including uncertain and variable ground conditions. As per Reilly (2005), for a complex infrastructure project like underground construction, it is very important to identify the risk events in the early phases of the project. A proper risk mitigation plan, if developed for identified risks, would ensure better and smoother achievement of project goals within the specified time, cost and quality parameters. Further, it would also ensure better construction safety throughout the execution and operational phase of the project.

Mulholand and Christan (1999) explain that due to the complexity and dynamic environments of construction projects, certain circumstances are created which result in a high degree of uncertainty and risk. Often these risks are compounded by demanding time constraints. Dey (2001) developed an Integrated Project Management Model for the Indian petroleum industry where he incorporated risk management into the conventional project management model and cited it as an integral component of project management. But Dey (2001) carried out the risk analysis by finding out the respective likelihoods of the identified risks which were found to have a summation of 1 for the respective work packages on a local percentage (LP) basis. The summation of the likelihoods of all the concerned work packages was found to be equal to 1 on a global percentage (GP) basis. Nehru and Vaid (2003) carried out the risk analysis with similar concepts. As per Roetzheim (1988) as quoted by Nicholas (2007), the likelihood of the identified risks can have a value ranging from 0 to 1, which indicates a 0% or a 100% chance of occurrence. But the weightage associated with all risk sources for a work package / activity is always equal to 1. The product of the likelihood and the respective weightages is equal to the cumulative likelihood factor (CLF).

Dey and Ogunlana (2002) describe that conventional project management techniques are not always sufficient to ensure time, cost and quality achievement of a large scale construction project, which may be mainly due to changes in scope and design, changes in government policies and regulations, unforeseen inflation, underestimation and improper estimation. Such projects which are exposed to such risks and uncertainties can be effectively managed with the application of risk management throughout the projects' life cycle. Dey (2002) developed a tool for risk analysis, also through the analytic hierarchy process (AHP) which is a multiple attribute decision making technique and decision tree approach. Rahman and Kumaraswamy (2002) carried out their research on joint risk management (JRM). Moreover, they generally preferred to assign reduced risks from either one or both contrasting parties to JRM, rather than shifting more risks to the other party. This is indicative of the fact that more collaborative effort and team based work can reduce the risk component of a project. Jannadi and Almishari (2003) developed a risk assessor model (RAM) for assessing the risk associated with a particular activity and tried to find out a justification factor for the proposed remedial measure for risk mitigation. Ward and Chapman (2003) in their research work made an argument indicating that all current project risk management processes induce a restricted focus on the management of project uncertainty. Zoysa and Russel (2003) developed a knowledge based approach for risk management. According to them effective risk management is a function in the successful planning and execution of large infrastructure projects.

3. Case study

The project considered for analysis is the construction of an underground corridor for metro rail operations in the capital city of an emerging economic nation in South Asia. Phase-I of the project is about 65 kms with 59 stations. The estimated capital cost of Phase-I is about

INR 105 billion. The project under study for this research work is a part of Phase I. The scope of work is the design and construction of a 6.6 km underground metro corridor with six underground stations and a twin tunnel system. The underground stations are referred to as S_1, S_2,…. S_6. Here S_6 is the terminal station equipped with an over-run tunnel (where an up train can be converted to a down train). The client is a public sector company floated jointly by the State and Central Government. The principal contractor is a Joint Venture (JV) of three foreign contractors and two domestic contractors. The type of contract is a Design Build Turnkey (DBT) where the principal contractor is required to design the underground corridor and execute the project. The project cost for the execution of 6.6 kms is about INR 18 billion. The contract period is about five years (exclusively for execution). The feasibility phase of the project is an additional five years. The activity chart of the sample stretch under analysis consisting of the tunnel connecting two stations S_5 and S_6, S_6 station box and the over-run tunnel succeeding S_6 station box is provided in Table 1. The corresponding network diagram is given in Figure 1. Some additional project details are furnished in Appendix 1.

Table 1: Major Activities and their Time Estimates in the Underground Corridor Construction Project (Terminal Station S_{6})

Activity	Description	Immediate Predecessors	Duration (Days)	ES	EF	LS	LF
A	Feasibility studies	-	1875	0	1875	0	1875
B	Design	A	295	1875	2170	1985	2280
C	Technology selection	A	90	1875	1965	1875	1965
D	Traffic diversion	B,E	475	2280	2755	2280	2755
E	Utility diversion	C	315	1965	2280	1965	2280
F	Survey works	B,E	290	2280	2570	2821	3111
G	Shoulder / King piles	D	356	2755	3111	2755	3111
H	Timber lagging	C	240	1965	2205	2871	3111
I	Soil excavation	G,F,H	330	3111	3411	3111	3441
J	Rock excavation	L,R	165	2655	2820	3276	3441
K	Fabrication and erection of construction decks	C	170	1965	2135	2941	3111
L	Fabrication and erection of steel struts	C	690	1965	2655	2421	3111
M	Rock anchor installation	N,O	285	2280	2565	3156	3441
N	Shotcreting & rock bolting	L,R	120	2655	2775	2871	2991
O	Subfloor drainage	Q	170	2110	2280	2821	2991
P	Water proofing	I,K,J,M	120	3441	3561	3441	3561
Q	Diaphragm wall construction	C	145	1965	2110	2604	2749
R	Top down construction	Q	122	2110	2232	2749	2871
S	Permanent structure	N,O	570	2280	2850	2991	3561
T	Mechanical / Electrical installations & services	P,S	225	3561	3786	3561	3786
U	Backfilling & restoration works	N,O	225	2280	2505	3561	3786

ES: Early Start; **EF**: Early Finish; **LS**: Late Start; **LF**: Late Finish

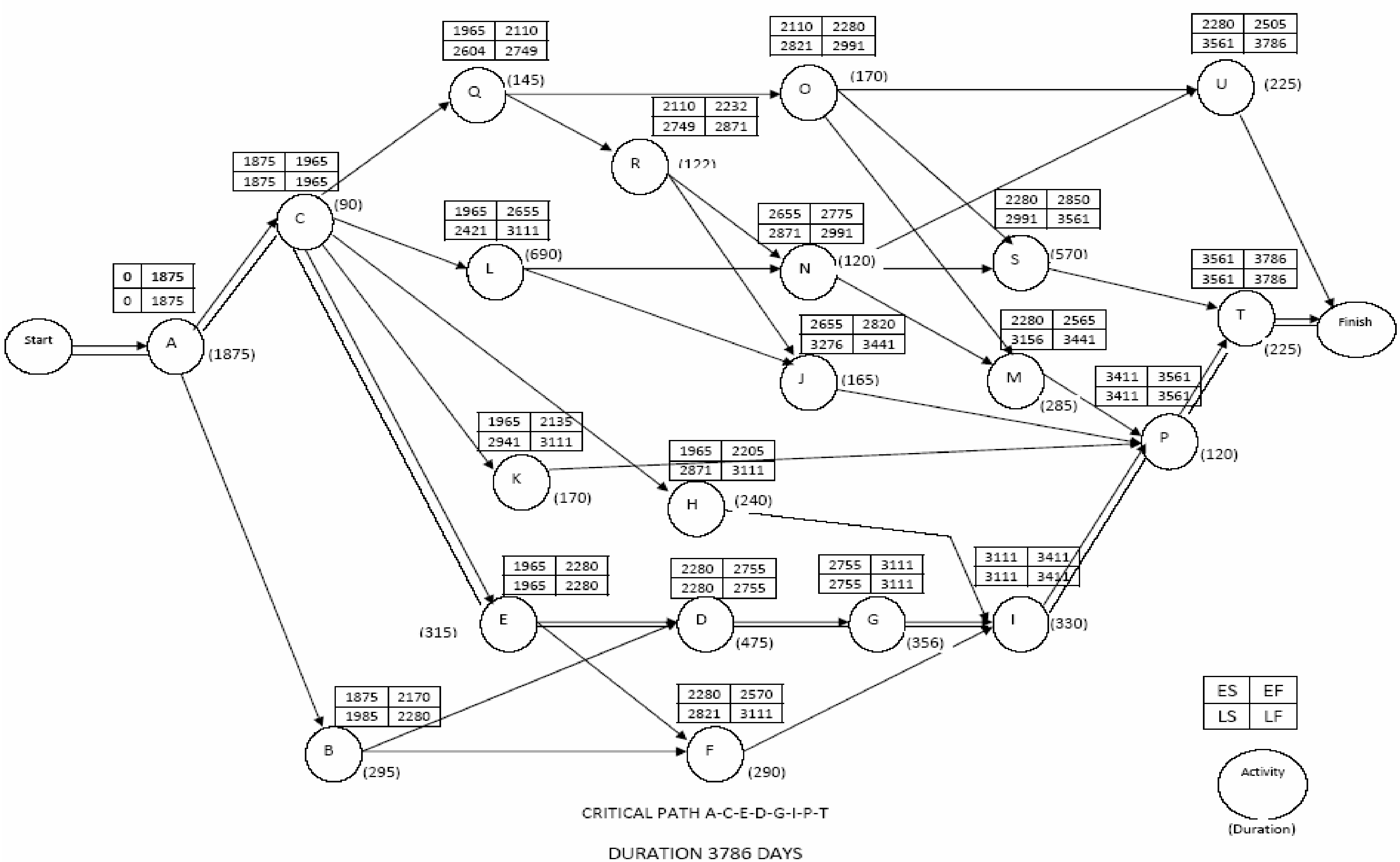


Figure 1: Network Diagram for Underground Corridor Construction Project

4. METHODOLOGY

Risk Analysis by Expected Value Method (EVM)

We assume a network of deterministic time and cost. We also assume that the critical path model network has "N" activities which are indicated by j = (1…… N) and there are "M" risk sources indicated by i = (1…..M). We extend the work of Roetzheim (1988) and Nicholas (2007), and explain, in this section, the concept of risk analysis by the Expected Value Method (EVM).

We define 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

BTE_j : Base Time Estimate for j th activity

BCE_j : Base Cost Estimate for j th activity

CC_j : Corrective Cost for j th activity

CT_j : Corrective Time for j th activity

RC_j : Risk Cost for j th activity

RT_j : Risk Time for j th activity

EC_j : Expected Cost for j th activity

ET_j : Expected Time for j th activity

Base time estimate (BTE) of the project is the estimated basic project duration determined by critical path method of the project network. Similarly, the estimated basic cost of project determined by the cost for each activity is termed as the base cost estimate (BCE). The BTE and BCE data of all the major activities of the project have been obtained as per the detailed construction drawings, method statement and specifications for the works collected from the project. The corresponding corrective time (CT) or the time required to correct an activity in case of a failure due to one or more risk sources for each activity and their corresponding corrective cost (CC) have been estimated based on the personal experiences of the first author and have been tabulated. An activity may have several risk sources each having its own likelihood of occurrence. The value of likelihood should range between 0 through 1. The likelihood of failure (L_{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. The summation of the weightages should be equal to 1.

$$\sum_{i=1}^{M} W_{ij} = 1 \text{ for all } j \; (j = 1 \ldots N) \quad \ldots \qquad (1)$$

The weightages can be based on local priority (LP) where the weightages of all the sub-activities of a particular activity equal 1. Also, weightages can be based on global priority (GP) where the weightages of all the activities of the project equal 1. The mean of all the responses should desirably be considered for analysis. Inconsistent responses can be modified using a second round questionnaire survey using the Delphi technique. The next step is to compute the risk cost (RC) and risk time (RT) of the activities of the project. RC and RT for an activity can be obtained from the following relationship:

Risk Cost for activity j $(RC)_j = (CC)_j \times L_j$ for all j. …… (2)

Risk Time for activity j $(RT)_j = (CT)_j \times L_j$ for all j …… (3)

The total risk time for an activity is the summation of the risk time of all the sub activities along the critical path.

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:

$$\text{Composite Likelihood Factor } (CLF)_j = \sum_{i=1}^{M} L_{ij} W_{ij} \text{ for all } j. \ \ldots\ldots \qquad (4)$$

$$0 \le L_{ij} \le 1 \text{ and } \sum_{i=1}^{M} W_{ij} = 1 \text{ for all } j$$

The impact of a risk can be expressed in terms of the effect caused by the risk to the time and cost of an activity. This time impact and cost impact can be considered as the risk time and risk cost of the activity. A similar computation as that of likelihood can be done for obtaining a single combined composite impact factor (CIF) by considering the weighted average as per the relationship given below:

Composite Impact Factor $(CIF)_j = \sum_{i=1}^{M} I_{ij} W_{ij}$ .... (5)

$0 \le I_{ij} \le 1$ and $\sum_{i=1}^{M} W_{ij} = 1$ for all j.

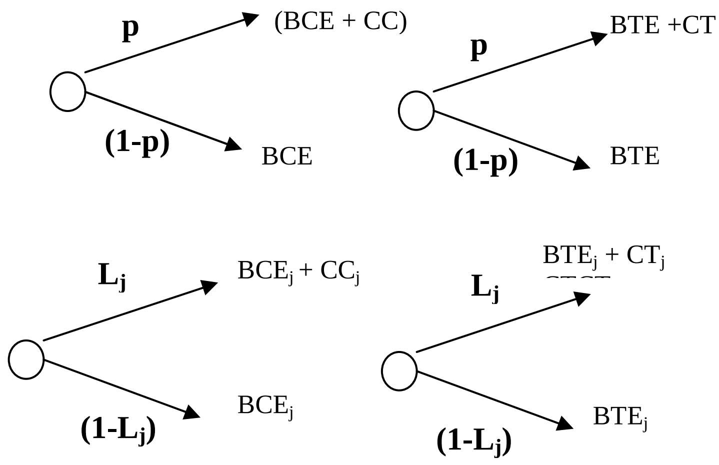
Risk consequence or severity can be expressed as a function of risk likelihood and risk impact. Thus the numerical value will range from 0 to 1. This severity can also be expressed in terms of qualitative rating as "no severity" for value 0 and "extremely high severity" for value 1. The numerical value of the Risk Severity (RS) is obtained from the below mentioned relationship:

Risk Consequence / Severity $(RS)_j = L_j \times I_j$ for all j ….. (6)

The risk consequence derived from this equation measures how serious the risk is to project performance. Small values represent unimportant risks that might be ignored and large values represent important risks that need to be treated.

The expected cost $(EC)_j$ and expected time $(ET)_j$ for each project activity and subsequently the computation of the expected project cost and time was carried out from the concept of the expected value (EV) of a decision tree analysis.

Expected value (EV) = probability of occurrence (p) [higher payoff] + (1-p) [lower payoff].



Expected Cost $(EC)_j = L_j\,(BCE_j + CC_j) + (1-L_j)\,BCE_j$

$= BCE_j + CC_j\,(L_j)$

$= BCE_j + RC_j$ for all j. …….. (7)

Expected Time $(ET)_j = L_j\,(BTE_j + CT_j) + (1-L_j)\,BTE_j$

$= BTE_j + CT_j\,(L_j)$

$= BTE_j + RT_j$ for all j. ……. (8)

5. CASE ANALYSIS

The sample stretch under analysis consists of a 530 metre(m) cut and cover tunnel connecting station S_5 and S_6, a 290m S_6 station box and a 180m cut and cover over run tunnel adjoining the S_6 station box. S_6 station being the terminal station, the down trains towards this station after leaving station S_5 will travel through the 530m cut and cover tunnel and enter the platforms of the terminal station S_6. After the commuters vacate the train at this terminal station, this down train will travel through the 180m over run tunnel and will be converted into an up line train which will travel from station S_6 to S_1.

The activities of the sample stretch under analysis consist of the installation and erection of temporary supporting and retaining structures to enable construction by cut and cover technology and for the construction of permanent structures like tunnels and station boxes which are RCC single boxes / twin boxes for tunnels and RCC boxes with intermediate concourse slab for station boxes.

We have considered some basic assumptions during the analysis. These assumptions are (i) the maximum cost overrun permissible is 25 % of the basic cost estimate beyond which the project becomes less feasible and (ii) the maximum permissible time overrun for infrastructure projects is about 30% of the base time estimate, beyond which the feasibility of the project reduces.

Table 2: Identification and Classification of Risks Involved in the Project

S. No.	Risk Classification Nomenclature	Risk Description
1	FPR	Feasibility Project Risk
2	PEPR 1	Pre execution Project Risk – Design Risks
3	PEPR 2	Pre execution Project Risk – Technology Risks
4	EPR 1	Execution Project Risk – Risks in traffic diversion works
5	EPR 2	Risks in utility diversion works
6	EPR 3	Risks in survey works
7	EPR 4	Risks in soldier piling and king piling works.
8	EPR 5	Risks in timber lagging works.
9	EPR 6	Risks in soil excavation works
10	EPR 7	Risks in rock excavation works
11	EPR 8	Risks in installation of construction decks
12	EPR 9	Risks in installation of steel struts
13	EPR 10	Risks in installation of rock anchors
14	EPR 11	Risks in shotcreting and rock bolting works
15	EPR 12	Risks in subfloor drainage works
16	EPR 13	Risks in waterproofing works
17	EPR 14	Risks in diaphragm wall construction
18	EPR 15	Risks in top down construction
19	EPR 16	Risks in permanent structure works
20	EPR 17	Risks in mechanical and electrical installation works
21	EPR 18	Risks in backfilling and restoration works

The common risk sources identified for all the activities A …. U as per Table 1 and Figure 1 are listed in Table 3 and a detailed description of the same is furnished in Appendix 2

Table 3: Common Risk Sources of the Project Activities

S No.	Risk Source Description
1	Risks due to delay in approval of detailed project report (DPR)
2	Land acquisition risks
3	Design risks
4	Technology selection risks
5	Approval and permit risks
6	Joint venture risks
7	Financial and investment risks
8	Political risks
9	Environment related risks
10	Geo technical risks
11	Major / minor accidents during execution
12	Unforeseen heavy rain
13	Force Majeure risks like flood, fire earthquake etc.
14	Labour agitation and strikes
15	Inflation risks
16	Risks due to delayed payment from client
17	Risks due to delayed payment to subcontractor

The risks identified under each activity have been listed and a detailed questionnaire consisting of all the identified risks as per the classification stated above has been framed. This questionnaire was circulated amongst 67 experts having adequate experience in underground construction projects or similar infrastructure projects. These experts were required to respond with respect to the likelihood of occurrence and the weightages associated with each risk based on their experience. The methodology for receiving the filled up questionnaires from the respondents was through personal approach, telephonic conversation, e-mails and post. The experts were Designers, Consultants, Deputy Project Leaders, Project Managers, Deputy Project Managers, CEOs, Managing Directors, Area Managers, people in charge of Quality assurance / Quality control, and Safety, Senior Engineers and Project

Engineers of the principal contractor of the above project, the client organization, the consulting organization, major sub-contractors of the above project and other ongoing metro rail projects within the country. Of around 67 experts, 45 had responded to this study and the mean of all the responses of respective risk likelihoods and their associated weightages in the related activities have been considered. The inconsistent responses were revised by conducting a second round questionnaire survey using the Delphi technique.

A sample of a part of a filled up questionnaire consisting of the likelihood of risks and the weightage associated with the identified risks for the feasibility project risk (FPR) is presented in Appendix 3. The value of likelihood (L_{ij}) varies from 0 to 1 and the sum of the weightages (W_{ij}) on local priority (LP) basis is 1 (0.121+0.185+0.155+0.295+0.075+0.169). The corresponding Composite Likelihood Factor (CLF)j $= \sum_{i=1}^{M} L_{ij} W_{ij}$ for all j (j = 1…. N) = 0.348 (refer Appendix 2)

Similar tables have been formulated for pre-execution project risk (PEPR 1 and PEPR2) and execution project risk (EPR 1 to EPR 18).

Application of EVM for Risk Analysis of the Project

The network diagrams consisting of the major activities of the project have been drawn and their activity times (early start, early finish, late start and late finish) have been calculated by forward and backward pass and then their critical path has been tracked out. The duration along the critical path is the longest duration path and is considered as the duration of the project. The BCE and BTE of each activity and sub-activity of the project have been calculated as per the actual site data. The corrective cost and time for each activity have been assumed as a certain percentage (25% to 75%) of BCE and BTE respectively depending upon the severity and casualty caused by that risk.

Each activity of the project as presented in figure 1 has been analyzed at the sub-activity level for computation of RC, RT, EC, ET and risk severity. The detailed analysis for computation of risk cost and time for all the activities of the project is presented in Table 4.

Table 4: Expected Cost and Time Analysis for the Project

Activity	$(CLF)_j$	Base Cost Estimate (BCE)j INR Million	Corrective Cost (CC)j INR. Million	Risk Cost (RC)j INR Million	Base Time Estimate (BTE)j Days	Corr-ective Time (CT)j Days	Risk Time (RT)j Days	Expected Cost (EC)j INR Million	Expected Time (ET)j Days	EC % Higher than BCE	ET % Higher than BTE
A	0.348	240	60	20.88	1875	1130	393.24	260.88	2268.24	8.7	20.97
B	0.356	110	32	11.392	295	245	87.22	121.392	382.22	10.36	29.57
C	0.27	40	10	2.7	90	85	22.95	42.7	112.95	6.75	25.5
D	0.319	50	11.9	3.7961	475	355	113.25	53.7961	588.25	7.59	23.84
E	0.262	100	82.4	21.5888	315	267	69.95	121.5888	384.95	21.59	22.21
F	0.186	10	8.66	1.61076	290	247	45.94	11.61076	335.94	16.11	15.84
G	0.28	220	176.465	49.4102	356	356	99.68	269.4102	455.68	22.46	28
H	0.252	20	15.975	4.0257	240	180	45.36	24.0257	285.36	20.13	18.9
I	0.377	150	122	45.994	330	205	77.29	195.994	407.29	30.66	23.42
J	0.419	80	56	23.464	165	140	58.66	103.464	223.66	29.33	35.55
K	0.398	120	108	42.984	170	113	44.97	162.984	214.97	35.82	26.46
L	0.367	300	245	89.915	690	485	178	389.915	868	29.97	25.8
M	0.345	50	49.2	16.974	285	250	86.25	66.974	371.25	33.95	30.26
N	0.343	80	70.3	24.1129	260	185	63.46	104.1129	323.46	30.14	24.41
O	0.306	60	58	17.748	170	130	39.78	77.748	209.78	29.58	23.4
P	0.384	120	83.2	31.9488	120	95	36.48	151.9488	156.48	26.62	30.4
Q	0.278	60	59.2	16.4576	145	115	31.97	76.4576	176.97	27.43	22.05
R	0.227	80	77.2	17.5244	122	88	19.98	97.5244	141.98	21.91	16.37
S	0.223	800	596.5	133.0195	570	415	92.55	933.0195	662.55	16.63	16.24
T	0.398	300	217.7	86.6446	225	180	71.64	386.6446	296.64	28.88	31.84
U	0.354	250	189.3	67.0122	225	163	57.7	317.0122	282.7	26.8	25.65
		3240	2329	729.20256	3786		884.47	3969.2026	4670.47	22.51	23.36

Note: Base time estimate and Risk time is considered as the time estimate along the critical path (refer Figure 1)

As per Figure 1 which represents the critical path diagram of the entire project of the underground corridor construction, and Table 4, for activity A (feasibility studies) the CLF is 0.348 as obtained from the feedback of the questionnaire survey (refer appendix 2). The base cost estimate $(BCE)_j$ for the activity feasibility studies (A) is INR 240 Million, the corrective cost $(CC)_j$ is INR 60 Million (assumed in consultation with experts); the base time estimate

$(BTE)_j$ is 1875 days; the corrective time $(CT)_j$ is 1130 days (assumed in consultation with experts).

As per equations (2) and (3), Risk cost $(RC)_j = 0.348 \times 60 \times 10^6$ = INR 20.88×10^6; Risk time $(RT)_j = 0.348 \times 1130$ days = 393.24 days. Thus as per equations (7) and (8), the expected cost $(EC)_j = BCE_j + RC_j$ = INR 260.88 Million, expected time $(ET)_j = BTE_j + RT_j$ = 2268.24 days.

A similar computation has been carried out for activities B, C, D….. and U (refer Table 4). Henceforth, the expected cost $(EC)_{project}$ of the entire project of underground corridor construction has been calculated as follows:

$$\text{Expected Cost } (EC)_{Project} = \sum_{j=A}^{U} EC_j$$

$$= \text{INR } 3969.20 \text{ Million}$$

Base Cost Estimate $(BCE)_{Project}$ = INR 3240 Million.

$$\text{Expected Time } (ET)_{Project} = (BTE)_{Project} + (RT)_{Project}$$

$$= 3786 + 884.47 \text{ days}$$

$$= 4670.47 \text{ days}$$

Table 5: Project Expected Cost and Time Analysis [Based on Questionnaire Survey]

Base Cost Estimate (INR Milion)	Risk Cost (INR Million)	Base Time Estimate (Days)	Risk Time (Days)	Expected Cost (INR Million)	Expected Time (Days)
3240	729.2	3786	884.47	3969.2	4670.47

Thus as per the analysis, the *EC* of the project is *22.51 % higher than the BCE* of the project. The *ET* of the project is 23.36 *% higher than the BTE*. As per the basic assumptions considered for risk management analysis the cost overrun should not exceed 25% of the estimated base cost and the time overrun should not be more than 30% of the estimated base time. Exceeding these limits would increase the chances of the project becoming less feasible. The risk management analysis predicts that the expected cost of the project is 22.51% higher than the estimated base cost. This situation is highly alarming as it is the upper limit of the permissible cost overrun. It requires meticulous planning and proper risk mitigation measures to enhance the probability of success of the project. The expected time predicted from the analysis is 23.36% higher than the estimated base time which is close to the upper limit of the permissible time overrun. Thus it is essential to judiciously follow the risk mitigation measures to ensure that the project is completed within the scheduled time frame.

Risk Severity Analysis using the Concept of CLF and CIF

Risk severity can be computed from equation (6). The product of the likelihood and impact of a risk can be considered as the severity of that risk. This concept can be extended for multiple risk sources in a work package, the likelihood and impact of which can be expressed in terms of CLF_j and CIF_j respectively. Thus for the underground corridor construction project, the risk severity of each major activity of the project is computed as presented in Table 6.

The scale for the classification of the risk severity is expressed as

Table 6: Risk Severity Classification

Severity	Classification
0.00 – 0.02	V. Low
0.03 – 0.05	Low
0.06 – 0.15	Medium
0.16 – 0.20	High
0.21 – 1.00	V. High

Table 7: Risk Severity Analysis of Total Project using the Concept of Composite Likelihood Factor (CLF) and Composite Impact Factor (CIF)

Description of project risk (activity)	Composite Likelihood Factor $(CLF)_j$	Composite Impact Factor $(CIF)_j$	Severity	
			Quantitative CLFj x CIFj	Qualitative
FPR (A)	0.348	0.875	0.305	V. High
PEPR 1 (B)	0.393	0.868	0.341	V. High
PEPR 2 (C)	0.27	0.829	0.224	V. High
EPR 1 (D)	0.319	0.784	0.25	V. High
EPR 2 (E)	0.262	0.809	0.212	V. High
EPR 3 (F)	0.186	0.832	0.155	Medium
EPR 4 (G)	0.28	0.827	0.232	V. High
PER 5 (H)	0.252	0.818	0.206	High
PER 6 (I)	0.377	0.863	0.325	V. High
EPR 7 (J)	0.419	0.816	0.342	V. High
EPR 8 (K)	0.398	0.842	0.335	V. High
EPR 9 (L)	0.367	0.828	0.303	V. High
EPR 10 (M)	0.345	0.86	0.298	V. High
EPR 11 (N)	0.343	0.827	0.284	V. High
EPR 12 (O)	0.306	0.806	0.247	V. High
EPR 13 (P)	0.384	0.858	0.329	V. High
EPR 14 (Q)	0.278	0.872	0.242	V. High
EPR 15 (R)	0.227	0.837	0.19	High
EPR 16 (S)	0.223	0.811	0.181	High
EPR 17 (T)	0.513	0.845	0.433	V. High
EPR 18 (U)	0.254	0.544	0.138	Medium

The risk severity analysis has also been carried out by PERT analysis and the outcome of both the EVM and PERT analysis in terms of the severity of the major activities of the project is presented in Table 8

Table 8: Outcome of Risk Severity analysis by Expected Value and PERT

V. High	High	Medium	Low
Design Technology selection Utility diversion Soldier Piles King Piles Soil / Rock excavation Diaphragm wall Steel struts Rock anchors Shotcreting and rock bolting	Traffic diversion Top down construction Timber lagging Mechanical & Electrical Works, Permanent Structure	Survey Backfilling & Restoration	Nil

Application of Monte Carlo Simulation

We apply the Monte Carlo simulation to predict the outcome of the expected time (ET) and expected cost (EC) of all the possible paths of activities as represented in the network diagram of the project (figure 1). The Monte Carlo simulation also takes into account the effects of the near critical paths becoming critical. By carrying out a detailed path analysis of the project network diagram, we observed that the path A-C-E-D-G-I-P-T has the longest duration of 3786 days. Hence this path is considered as the critical path of the project network (refer figure 1). The corresponding cost for the completion of activities along this path is INR 1220 Million. It is also observed that the probability of the successful completion of the project within the stipulated time and cost frame is only 4% (0.625 x 0.730 x 0.738 x 0.681 x 0.720 x 0.623 x 0.616 x 0.602 = 0.040). Path A-B-D-G-I-P-T is a near critical path with a probability of about 4.8% for successful completion within the stipulated time and cost frame. There are chances of this path becoming critical.

The application of the Monte Carlo simulation to the above path analysis resulted in the following outcome:

Table 9: Outcome of Path Analysis of the Project Network Diagram Applying Monte Carlo Simulation

Path	Activity / Node	Path duration (days)	Cost (Rs. Crores)
1	A-B-D-G-I-P-T	3676.17	119.28
2	A-C-E-D-G-I-P-T	3785.98	122.28
3	A-C-E-F-I-P-T	3244.88	96.17
4	A-C-H-I-P-T	2879.88	87.11
5	A-C-K-P-T	2479.67	82.09
6	A-C-L-J-P-T	3164.79	108.19
7	A-C-Q-R-J-P-T	2741.60	92.20
8	A-C-Q-O-S-T	3074.89	150.10
9	A-C-Q-O-U	2504.95	65.07

From the above analysis we observed that path 2 (A-C-E-D-G-I-P-T) has the longest duration of 3785.98 days and remains critical. The corresponding cost for the completion of all the activities along the critical path is INR 1222.8 Million. The probability of the successful completion of path 2 or the critical path within the scheduled time is 50%. The probability of the successful completion of the near critical path or path 1 within the scheduled time is 84.13% (Z = 1.009, P = 0.8413). Also the probability of the successful completion of all the paths within the scheduled time is 42.05% (P = 0.8413 x 0.5 x 1 x 1 x 1 x 1 x 1 x 1 x 1 = 0.4205)

Carrying out about 10,000 runs of the Monte Carlo simulation, the EC was found to have a value of INR 3532.9 Million and the ET of the project was found to be 4351.12 days.

Proposed Risk Management Model for the Underground Corridor Construction for Metro Rail

The generalized risk management model for the underground corridor construction for the metro rail is proposed on the basis of the detailed analysis carried out. This model can be effectively implemented in the ongoing and upcoming metro rail projects across the nation.

As a part of the formulation of risk mitigation strategies, the following risk response planning can be adapted by the project authority: (i) risk transfer, (ii) risk sharing (iii) risk reduction (iv) risk contingency planning and (v) risk mitigation through insurance.

6. CONCLUSION

Project risk management which primarily comprises schedule and cost uncertainties and risks should be essentially carried out for complex urban infrastructure projects such as the construction of an underground corridor for metro rail operations. In the current research work we found that the number of major and minor risks involved during the construction of the project, from the feasibility to the completion of the execution, are large, and if not treated or mitigated properly, the probability of successful completion of the project within the stipulated time and cost frame will reduce. This will have a direct impact on the efficiency and profitability of the organization.

As per the analysis carried out by EVM, based on the expert questionnaire survey, the expected project cost for the sample stretch under analysis (530 m tunnel from station S_5 to S_6, S_6 station box and 180 m over-run tunnel) is about 22.51% higher than the base cost estimate of the project. According to the basic assumptions made for the analytical procedure adopted, the maximum permissible cost overrun for the project is 25%. Thus if proper project risk management is not carried out by the authority, the project may result in a cost and time overrun which will ultimately reduce the feasibility of the successful completion of the project. The expected project time as obtained by the analysis is about 23.36% higher than the base time estimate of the project, the maximum permissible time overrun as per the basic assumptions being 30% of the base time estimate. This value is also quite alarming making the concerned authority feel the need for carrying out proper risk management for such complex infrastructure projects.

Hence considering the results of all the analyses carried out in this research work, it can be concluded that for complex infrastructure projects like that of an underground corridor construction, based on EVM, about INR 0.82 Million extra per day per station would be incurred if proper risk management is not followed to mitigate the anticipated risks. Thus for six underground stations for this 6.6 km underground metro corridor package approximately INR 4.92 Million extra per day will have to be incurred by the project authorities. A major limitation of the model adopted for analysis is that the entire model being probabilistic, the outcome of the analysis is largely dependent on the opinion of the likelihood and weightages of the identified risks obtained from the expert questionnaire survey. Also any sort of misinformation provided will result in erroneous results. Although at present, a very nominal percentage of identified risks can be insured under the existing "Contractors All Risk Policy", the potentiality of insurance and the means of making insurance a strong risk mitigation tool for the construction industry provide scope for future research.

The proposed risk management model will definitely benefit the ongoing metro corridor works and about 20 future anticipated metro projects in cities across the nation under study.

SCOPE OF FUTURE RESEARCH

As the nation under study is an emerging economy, there are proposals for several metro rail construction projects likely to come up in the next two decades. This study can be used as an aid to plan for the quantitative risk management for these projects. An integrated decision support system for underground corridor metro rail projects can also be developed based on the risk management model. As the concept is generic, we can extend the concept to several other types of complex infrastructure projects like highways, oil and gas refineries, airports, bridges, nuclear, thermal and hydro power plants and other forms of mass rapid transit system (MRTS) projects. The potentiality of insurance as a risk mitigation tool should also be explored.

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APPENDIX 1: Additional Project Details

Project Description	**Details**
Length of route (a) Tunnel (by Tunnel Boring Machine [TBM]) - 3811 m (b) Tunnel (by Cut & Cover method) - 937 m (c) Station boxes - 1821 m	6569 m
Average depth of stations	15 - 20 m below ground level
Typical width of stations	Average 20 m
Typical length of stations	275m to 300m
Design life	120 years for underground structures and 50 years for super structures
Major Scope of Civil Engineering Works (a) Excavation (soil) : (b) Excavation (rock) : (c) Concreting : (d) Reinforcement : (e) Strutting :	 10,90,000 cum. 2,15,000 cum. 3,00,000 cum. 47,500 MT 24,500 MT

APPENDIX 2: Sample Questionnaire for Feasibility Project Risk (FPR)

FPR 1: Feasibility Project Risk 1 – Risks in Preparation of Feasibility Report			
Risk Description	**Likelihood (L_{ij})**	**Weightage (LP) (W_{ij})**	**Impact (I_{ij})**
Delay in submission of preliminary feasibility report	0.15	0.029	0.65
Delay in approval for carrying out detailed feasibility study	0.20	0.030	0.75
Delay in preparation and submission of detailed project report (DPR)	0.20	0.018	0.85
Delay in approval of DPR	0.30	0.044	0.90
CLF = 0.027 CIF = 0.096		Total 0.121	
FPR 2: Resettlement and Rehabilitation Risks			
Resettlement site not accepted by affected parties	0.35	0.085	0.95
Resettlement site very costly	0.15	0.055	0.80
Litigation by affected parties	0.45	0.035	0.95
Resistance and agitation by political parties	0.5	0.01	0.90
CLF = 0.059 CIF = 0.167		Total 0.185	
FPR 3: Pre-investment Risks			
Cancellation of project after bidding	0.1	0.023	0.90
Delay in setting of consortium(JV)	0.35	0.052	0.95
Prolonged delay in project finalization	0.3	0.08	0.80
CLF = 0.045 CIF = 0.134		Total 0.155	

FPR 4: Land Acquisition Risks			
Risk Description	**Likelihood**	**Weightage**	
Political interference	0.55	0.013	0.9
Delay in finalizing temporary rehabilitation schemes	0.4	0.055	0.85
Public interference for changing the alignment	0.25	0.055	0.9
Interference of environmental activists	0.4	0.012	0.9
Delay due to interdepartmental issues	0.35	0.03	0.9
Delay in construction of diversion roads for existing traffic	0.2	0.014	0.85
Problems with the physical possession of land	0.65	0.116	0.95
CLF = 0.136 CIF = 0.264		Total: 0.295	
FPR 5: Financial Closure Risks			
Project not bankable	0.2	0.035	0.85
Lenders not comfortable with project viability	0.15	0.005	0.75
Adverse investment climate	0.1	0.035	0.80
CLF = 0.011 CIF = 0.061		Total: 0.075	
FPR 6: Permit and Approval Risks			
Delay in contractual clearances	0.2	0.023	0.80
Delay in project specific orders and approvals	0.25	0.019	0.85
Delay in the approval of major utilities (telecom cables, electrical cables, storm water drains, sewer lines, filtered and unfiltered water lines)	0.45	0.049	0.90
Delay in clearance from environmental and forest departments	0.5	0.078	0.95
CLF = 0.070 CIF = 0.153		Total: 0.169	
$CLF_{Feasibility}$ = 0.348 (0.027 + 0.059 + 0.045 + 0.136 + 0.011+ 0.070) $CIF_{Feasibility}$ = 0.875 (0.096 +0.167+0.134 + 0.264 + 0.061 + 0.153)		Grand Total: 1	