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Development of a Risk Management Framework for Tunnel Construction in India

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***Abstract*—The growth of Tunnel Construction industry made significant improvement over the past few decades. This is fundamentally due to the increasing investments in road, rail and hydropower sectors. However, the tunnel construction industry in our country faces many challenges. This many a times lead to the incompletion of these projects, and ultimately its cost overrun and time overrun. A successful tunnel project is possible only if the risks associated with the project are identified, evaluated and managed. The main objective of this paper includes risk assessment and management of tunneling projects in developing countries like India. The procedure followed in this paper involves risks identification through literature surveys and interviews with experts, preparation of risk questionnaire to determine probability and severity of risk involved in various phases of the project, analysing the risks and suggesting risk mitigation measures for the major risks involved in the project. Case studies are also carried out to give a better insight in to the study.**

Keywords— Risk Analysis, IMP.I(Importance Index Technique), Risk Matrix, Risk Register, Tunneling Projects

I. INTRODUCTION

Tunnelling as a unique branch of civil engineering is described by high dangers during project execution. Tunnelling and underground construction works impose hazards on all parties involved not only on those directly engaged with the task. Especially in residential areas the effect has been drastic on the local residents as well as on the surrounding buildings.

The inherent risks include ground and groundwater conditions, cost overrun delays, large scale accidents also there is a risk that problems which the tunnel project cause to the public might result in public protest which may affect the project. These risks are generally solved through appropriate risk assessment and risk mitigation methods. However, the lack of appropriate methods of risk management in our country has led to the cost overrun and time over run of many of the tunnelling projects. The application of risk assessment and management in the tunnel construction industry is the need of this time due to the ever increasing complexity of the tunnelling projects and due to the ever increasing pressure for cost reduction and construction duration reduction.

II. OBJECTIVES

The main objectives of this paper are:

- To identify the major internal and external risks that affect the growth of the tunnel construction industry.
- The evaluation of risks so as to prioritize them for effective risk management.
- Development of a risk management model which uses appropriate techniques to reduce risks in tunnelling.

III. LITERATURE SURVEY

- Rakhi Arora et al. (2016**),** identified various technical risks encountered with at the time of excavation. The instability of the ground is one of the main dangers that must be catered to do. It arises due to adverse orientation of the joint and fracture plane and due to the presence of cohesive sands. A case study was also conducted at Azadpur where during excavation bed rock was discovered instead of continuous soil strata.
- Cagatay, (2015) in his paper has proposed what the hazards that would be encountered during tunnel construction by Tunnel Boring Method (TBM) are. A Hazard Analysis is conducted to sort out and categorise risks with high scores. The results showed that hazards with high scores were basically of these four categories which include excavation, support induced accidents geological conditions axillary works and project contract.
- Vishal Kumar Gupta et al. (2017) mentioned in their study that the risk management techniques of Indian Construction companies have large setbacks for the process, since it was evident from the time and cost overrun numbers. They highlighted the risk factors involved in typical tunnelling which include the construction risk, management risks, political, social economic risks and force majeure. Risk quantification methodologies such as Monte Carlo Simulation (MCS) and Judgemental Risk Analysis (JRA) process were proposed. A case study was conducted to apply the proposed risk quantification methodology to help organisations.
- Surabhi Mishra et.al. (2016) in their study suggested various critical risk factors involved in construction projects. Basically, risks were classified as engineering and non-engineering risks. The former is predictable while the latter is unpredictable. Hence those risks that are predictable should be forecasted in the initial phases of the project. The unpredictable risks should also be taken into account so to avoid substantial negative effects on the cost, time and quality of the project. It was concluded in this study that identifying risks earlier during the initial phases of construction will lead to accurate findings about cost and time overrun
- Soren Degn Eskesen et al. (2004) put forward guidelines for risk management in tunneling. This topic elaborates on how modern-day industries practise risk assessment. It describes the stages of risk assessment throughout the project cycle right from the conceptual

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stage including the early design phase, Tendering and Contract negotiation phase and the execution phase. It also contains some general components of risk management and a brief introduction to the typical risk management tools.

IV. RISK MANAGEMENT FRAMEWORK

Risk Management is a systematized method of identification, analysation and response to project risk. In other words, it is a maximization of the probability and outcomes of positive events and minimisation of the probability and outcomes of negative events on the project objectives. Refer to Fig. 1 for the flow chart of a risk management framework.

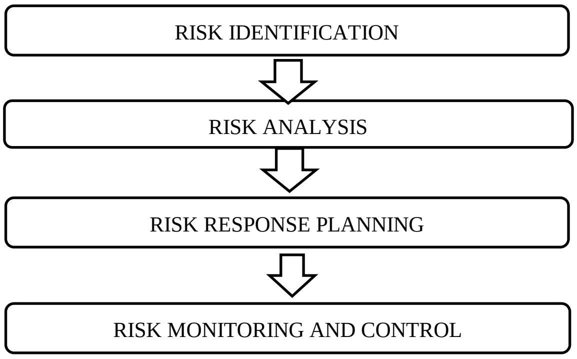

Fig .1. Risk Management Framework

V. RISK IDENTIFICATION

Risk identification is the process of identifying the risks that affect the project objectives. It is an iterative process in which the first step is done by the risk management team, the second iterative process is done by the primary stakeholders and the final iterative process is done by persons who are not in the project. In this paper risks affecting the tunneling projects were identified through literature surveys, case studies and by conducting interviews with experts in the field of construction. The risks identified are shown in the Table 1.

VI. RISK ANALYSIS

It is the process in which risks are prioritized based on their effect on project objectives. The inputs in the process would include the identified risks and assumptions. After using the appropriate tools, the output is obtained i.e. a risk ranking for the project. The technique used for risk analysis in this paper is Importance Index (IMP.I) Technique.

A. Questionnaire Survey

Basically, experts are selected from the group of people who have experience of being consultants in the construction field. A questionnaire was prepared based on the identified variables from various literature surveys and exert judgements. It was made in three sections.

TABLE I. RISK BREAKDOWN STRUCTURE

EXTERNAL RISKS	**INTERNAL RISKS**
Change in government policies which adversely affects the project	Design faults
Strikes and labour disputes	Cave in collapse
Inflation/price escalation	Tunnel flooding
Land disputes	Natural obstruction (boulder bed) and manmade obstruction (abandoned foundation):
Site condition causing problems- Loose soil, hard soil etc.	Risk due to over burden
Landslides getting working buried, Earthquakes, Storms, Floods	Poor communication of design in the drawing
	Change orders/ Deviation proposals
	Lack of cash flow
	Accident to contractor's or employer's men or third party
	Damage as to property - neighboring property during execution
	Defective material and equipment
	Risk of rotating parting of equipments
	Gas leakage or spillage of dangerous goods or chemicals
	Fall of materials or equipment
	Lack of oxygen within the confined spaces
	Low productivity of labour/ machine
	Fall of persons into the trenches
	Delay in approvals
	Delay of mobilization of resources
	Ability to deal with local labour union
	Communication problem with the employer
	Uncertainty in job description specified in the contract

Section 1 covers the personal details. It includes the personal information like Name of the respondent, type of the organization he/she belongs to, type of work his/her organization does, His/her position in the organization and their construction experience.

Section 2 covers the external risks attained from the reports. Responses on external risks regarding its frequency and severity were collected on Likert scale of 1 to 5

Section 3 covers the internal risks attained from the reports. Responses on internal risks regarding its frequency and severity were collected on Likert scale of 1 to 5

Basically, a five point Likert scale is used for the analysis of risks in this project as shown in Table II and Table III. The definition for different ratings given for the likelihood of risk is given in Table IV (Pumann et al, 2008). The definition for different ratings given for the impact of risk on cost and time of project is given in Table V and Table VI as referred from the Project Management Book of Knowledge (PMBOK). The experts were asked to rate the risks on a scale of one to five. The frequency of occurrence and the impact on both cost and time were analysed.

TABLE II. LIKERT SCALE FOR PROBABILITY OF OCCURRENCE

Rare	**Unlikely**	**Possible**	**Likely**	**Most likely**
1	2	3	4	5

TABLE III. LIKERT SCALE FOR SEVERITY OF RISKS

Insignificant	Minor	Moderate	Major	Extreme
1	2	3	4	5

TABLE IV. DEFINITION OF VARIOUS FREQUENCY RATING OF RISKS (Pumann et al, 2008)

Rare	Occurs once in a duration greater than 5 years
Unlikely	Occurs once in 5 years
Possible	Occurs once a year
Likely	Occurs once in a month
Most Likely	Occurs frequently in a week

TABLE V. DEFINITION FOR IMPACT OF RISK ON PROJECT COST (PMBOK)

Insignificant	Insignificant cost increase
Minor	<5% cost increase
Moderate	5 to 10% cost increase
Major	10 to 20% cost increase
Extreme	>20% cost increase

TABLE VI . IMPACT OF RISK ON PROJECT SCHEDULE (PMBOK)

Insignificant	Insignificant schedule slippage
Minor	Schedule slippage < 5%
Moderate	Schedule slippage 5 to 10%
Major	Schedule slippage 10 to 20%
Extreme	Schedule slippage greater than 20%

A total of 100 questionnaires were send and feedback from 71 experts were received. Out of the 71 responses 45 were complete and 26 were incomplete yielding a completion rate of 63%. It is satisfactory for the purpose of this research. In addition to these surveys, face to face interviews were also conducted with consultants and designers.

Respondents include experts in the field of construction which includes site engineers and construction managers. The range of experience in the field varied from 2 to 20 yrs. Respondents were targeted through random sampling. Questionnaires were sent by mail or given personally. Since the experts of greater years of experience have better knowledge, their responses are being given greater weightage as shown in the Table VII below.

Table VII. WEIGHTAGE GIVEN TO THE RESPONSE COLLECTED

SI. No	No of years of experience in the construction field	Weightage	No of responses
1	0-10	1	17
2	>10	2	28

B. *Importance Index (IMP.I) Technique*

In this technique the calculations are done by measuring the severity index and frequency index as below. (Mamata Rajgor,2016)

Frequency Index: A formula used to rank risk based on the frequency of occurrence as identified by the participants.

$$\text{Frequency Index (F.I) (\%)} = \sum a(n/N) * 100/5$$

Where a is the constant expressing weightage given to each response (ranging from 1 for rare to 5 for most likely) n is the frequency of response and N is the total number of responses.

Severity Index: A formula used to rank risk based on the severity of occurrence as identified by the participants.

$$\text{Severity Index (F.I) (\%)} = \sum b(n/N) * 100/5$$

Where b is the constant expressing weightage given to each response (ranging from 1for insignificant to 5 for extreme) n is the frequency of response and N is the total number of responses.

Importance Index: The importance index of each risk is calculated as a function of both frequency and severity indices.

$$\textbf{Importance Index (\%) = (FI*SI)/100}$$

The importance index helps us to determine the ranking of risks. The ranking of risks based on the impact on cost and time are tabulated in Table VIII and Table IX

C. *Risk Matrix*

A risk matrix is also known as the severity matrix and it helps to improve the visibility of risks. A risk matrix is an important tool that has to be implemented in every project that are critical to the exposure of risks. A risk matrix consist of a series of squares and each risk is assigned a square based on its corresponding frequency and severity. Fig. 2 is an example of a typical risk matrix.

		IMPACT ON PROJECT OBJECTIVE (cost/time)				
		0.1	0.3	0.5	0.7	0.9
PROBABILITY	0.1	0.01	0.03	0.05	0.07	0.09
	0.3	0.03	0.09	0.15	0.21	0.27
	0.5	0.05	0.15	0.25	0.35	0.45
	0.7	0.07	0.21	0.35	0.49	0.63
	0.9	0.09	0.27	0.45	0.63	0.81

Blue: Low; Pink: Medium; Green: High; Yellow: Extreme

Fig. 2 Probability Impact Matrix (PMBOK)

TABLE VIII: RANKING BASED ON SEVERITY OF COST

RISK ID	Risk Factors	Frequency Index	Severity Index	Importance Index	Ranking
R1	Change in government policies which adversely affects the project	0.66	0.69	0.45	6
R2	Strikes and labour disputes	0.73	0.63	0.46	5
R3	Inflation/price escalation	0.77	0.71	0.55	2
R4	Land disputes	0.71	0.66	0.47	3
R5	Site condition causing problems-Loose soil, hard soil etc	0.76	0.75	0.57	1
R6	Site condition causing problems-High water table	0.69	0.65	0.45	7
R7	Landslides getting working burried, Earthquakes, Storms, Floods	0.65	0.68	0.44	9
R8	Design faults (design by	0.62	0.70	0.43	11

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	the contractor)				
R9	Cave in collapse	0.69	0.67	0.46	4
R10	Tunnel flooding	0.59	0.59	0.35	17
R11	Natural obstruction (boulder bed) and manmade obstruction (abandoned foundation)	0.59	0.54	0.32	26
R12	Risk due to over burden	0.60	0.52	0.31	27
R13	Poor communication of design in the drawing	0.60	0.56	0.34	21
R14	Change orders/ Deviation proposals	0.69	0.64	0.44	8
R15	Lack of cash flow	0.71	0.59	0.42	12

R16	Accident to contractor's or employer's men or third party	0.66	0.59	0.39	14
R17	Damage as to property - neighbouring property during execution	0.67	0.54	0.36	16
R18	Defective material and equipment	0.64	0.53	0.34	19
R19	Risk of rotating parting of equipments	0.61	0.54	0.33	24
R20	Gas leakage or spillage of dangerous goods or chemicals	0.62	0.54	0.33	22
R21	Fall of materials or equipment	0.65	0.51	0.33	23
R22	Lack of oxygen within the confined spaces	0.65	0.52	0.34	20
R23	Low productivity of labour/ machine	0.66	0.58	0.38	15
R24	Fall of persons into the trenches	0.62	0.52	0.32	25
R25	Delay in approvals	0.71	0.61	0.44	10
R26	Delay of mobilization of resources	0.68	0.59	0.4	13
R27	Ability to deal with local labour union	0.65	0.54	0.35	18
R28	Communication problem with the employer	0.6	0.47	0.28	29
R29	Uncertainty in job description specified in the contract	0.6	0.48	0.29	28

TABLE IX. RANKING BASED ON SEVERITY OF TIME

Risk ID	Risk Factors	Frequency index	Severity Index	Importance Index	Ranking
R1	Change in government policies which adversely affects the project	0.66	0.69	0.46	7
R2	Strikes and labour disputes	0.73	0.69	0.50	2
R3	Inflation/price escalation	0.77	0.63	0.49	4
R4	Land disputes	0.71	0.70	0.50	3
R5	Site condition causing problems- Loose soil, hard soil etc	0.76	0.72	0.55	1
R6	Site condition causing problems- High water table	0.69	0.63	0.44	9
R7	Landslides getting working burried, Earthquakes, Storms, Floods	0.65	0.66	0.43	13
R8	Design faults (design by the contractor)	0.62	0.70	0.43	11
R9	Cave in collapse	0.69	0.63	0.44	10
		0.59	0.57	0.33	
R10	Tunnel flooding	0.00	0.00	0.00	22
R11	Natural obstruction (boulder bed) and manmade obstruction (abandoned foundation)	0.59	0.54	0.32	25
R12	Risk due to over burden	0.60	0.56	0.34	20
R13	Poor communication of design in the drawing	0.60	0.58	0.35	18
R14	Change orders/ Deviation proposals	0.69	0.62	0.43	12
R15	Lack of cash flow	0.71	0.65	0.46	6
R16	Accident to contractor's or employer's men or third party	0.66	0.56	0.37	15
R17	Damage as to property - neighbouring property during execution	0.67	0.56	0.37	16
R18	Defective material and equipment	0.64	0.53	0.34	21
R19	Risk of rotating parting of equipments	0.61	0.51	0.31	26
R20	Gas leakage or spillage of dangerous goods or chemicals	0.62	0.52	0.33	24
R21	Fall of materials or equipment	0.65	0.51	0.33	23
R22	Lack of oxygen within the confined spaces	0.65	0.52	0.34	19
R23	Low productivity of labour/ machine	0.66	0.61	0.40	14
R24	Fall of persons into the trenches	0.62	0.48	0.29	29
R25	Delay in approvals	0.71	0.66	0.47	5
R26	Delay of mobilization of resources	0.68	0.65	0.44	8
R27	Ability to deal with local labour union	0.65	0.57	0.37	17
R28	Communication problem with the employer	0.60	0.50	0.30	28
R29	Uncertainty in job description specified in the contract	0.60	0.51	0.31	27

By referring to the risk matrix in Fig.2 we can categorize the risks on both cost and time as in Fig. 3 and Fig. 4

PROBABILITY		IMPACT ON COST				
		0.1	0.3	0.5	0.7	0.9
	0.1					
	0.3					R22, R20, R18, R13, R19
	0.5				R23, R26, R27	R15, R25
	0.7			R10, R16, R17,	R3, R4, R5, R1, R2, R9, R6	
	0.9		R28, R29, R11, R12, R24, R21	R7, R8, R14		

Fig.3. Probability Impact Matrix for cost

PROBABILITY		IMPACT ON TIME				
		0.1	0.3	0.5	0.7	0.9
	0.1					
	0.3					R21, R20, R24
	0.5				R13, R16, R17, R27, R22,	R9, R14, R26
	0.7			R10, R12, R18, R23	R1, R2, R3, R4, R5, R15, R25	
	0.9		R28, R29, R19, R11	R6, R7, R8		

Fig. 4. Probability Impact matrix for time

VII . RESULTS AND DISCUSSIONS

Extreme risks are those that have the highest impact indices. The extreme risks as observed from the risk matrix are graphed in figures Fig.5 and Fig.6 as below:

By comparing both the tables above we find that, the critical risks that cause serious impact on cost and time are similar. Though there are various factors that affect the smooth progress of tunnelling, the most critical that are common in most projects and result in the cost and time overrun include: Change in government policies, strikes and labour disputes, inflation, site problems force majeure, design faults, cave in collapse lack of

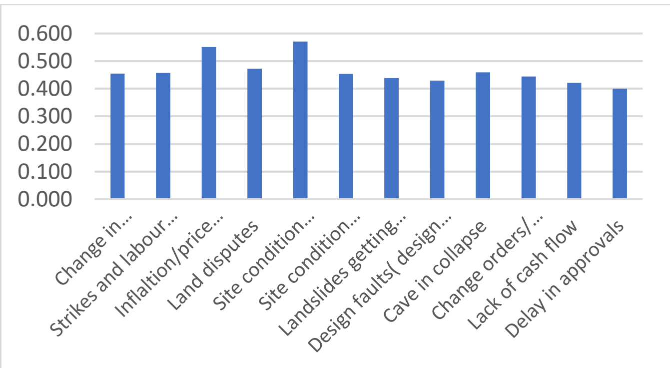

Fig. 5 Extreme risks affecting Project Cost

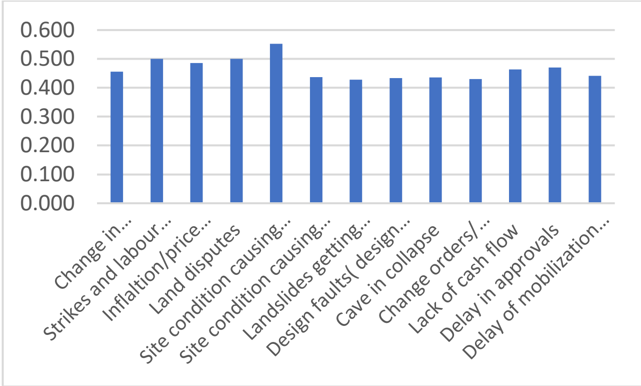

Fig.6 Extreme Risk causing slippage in schedule of the project

cash flow. delay in approvals and delay in mobilization of resources.

Moreover almost all the risks identified through the survey come either in the high or extreme risk category. Hence proper response strategy and proper preparedness is required to manage all the risks identified. It is clear from the above study that the critical risks are those that are mostly from the external sources. Though the external risks are caused due to reasons not linked with the project and it is beyond the control of the project manager, safety measures can be implemented that helps in reducing its impact on the project objectives. The strategy to manage these high and extreme risks should be carefully selected since the success of the project depends on the capacity to face risks.

VIII . CASE STUDIES

Since this project is concerned with the risk management in our country, a better understanding can be possible only through going through various tunneling projects that had been undertaken here. Some of the various tunneling projects that faced challenges are included in this case study and they include BMRCL tunnel Phase I, Atal Tunnel and Kuthiran Tunnel.

From Table XI it is clear that the risks faced during the execution of these projects are same as the extreme risks that was obtained in our risk analysis earlier. Since these risks were not identified in the earlier stages of the project, they caused adverse impacts on the project objectives such as time cost and quality. Hence proper risk identification and response techniques are required for the successful completion of the tunnel construction projects.

TABLE X. PROJECT RISK REGISTER

Risk ID	Risk Description	Ranking based on cost	Ranking based on Time	Risk Owner	Response Strategy	Details
R5	Site condition causing problems- Loose soil, hard soil etc	1	1	Owner	Mitigate	• Confirmatory geological investigation done in detail with appropriate focus on the GBR and GDR reports.
R3	Inflation /price escalation	2	4	Contractor	Transfer	• Escalation Clause • Price contingency in the bid
R4	Land disputes	3	3	Owner	Avoid	• Careful site selection backed by investigation of history. • Addressing all environmental issues before the bid process, including impact assessment. • Interfacing with concerned departments to ensure land approvals in place or face least obstacles. • Community consultations to ensure least resistance from local population.
R9	Cave in collapse	4	10	Contractor	Avoid	• Provide adequate shoring to prevent collapse of soil, this should be regularly checked. • Shear zones are difficult to be located, exploration by drifting should be adopted for obtaining proper information.
R2	Strikes and labour disputes	5	2	Owner	Mitigate	• Use risk monitoring tools to track labour issues • Bridge the gap between the labour and the management
R1	Change in government policies which adversely affects the project	6	7	Owner	Accept	• Develop plans for emergency situations like wars • Political risks can be insured against through international agencies and government bodies • Maintaining good relationship with powerful groups • Avoid misconduct such as environmental pollution, bribery and cultural conflicts
R6	Site condition causing problems- High water table	7	9	Owner	Mitigate	• Confirmatory geological investigation done in detail. • Dewatering by well pointing technique done to prevent accumulation
R14	Change orders/ Deviation proposals	8	12	Owner - Contractor	Avoid	• Establish a quality control process • Increase coordination between the owner and contractor • Establish a change order process upfront • Include more detail in the project design
R7	Landslides getting working buried, Earthquakes, Storms, Floods	9	13	Owner	Transfer	• Insure all force majeure risks. • Obtain Governments guarantees to adjust tariff or extend concession period.
R25	Delay in approvals	10	5	Owner/Contractor	Avoid	• Flexibility should be maintained in the timeline. • Identify and document the source of delay and find solution • Prepare a RACI matrix
R8	Design faults (design by the contractor)	11	11	Architect	Mitigate	• Performance Guarantee • Retention Bond • Hire experienced surveyors and designers for design
R15	Lack of cash flow	12	6	Contractor	Mitigate	• Create a cash flow projection for the project so to monitor well

TABLE XI. CRITICAL RISK FACTORS OF VARIOUS TUNNEL PROJECTS

SI No	Critical Risk Factors	BMRCL Phase 1Tunnel Construction 2017	Atal Tunnel (2014)	Kuthiran Twin Tunnel
1	Site condition causing problems- Loose soil, hard soil etc	✓	✓	✓
2	Inflation /price escalation	✓	✓	
3	Land disputes	✓		✓
4	Cave in collapse			
5	Strikes and labour disputes		✓	✓
6	Change in government policies which adversely affects the project			
7	Site condition causing problems-High water table	✓		
8	Change orders/ Deviation proposals			✓
9	Landslides getting working buried, Earthquakes, Storms, Floods		✓	
10	Delay in approvals	✓		✓
11	Design faults (design by the contractor)		✓	
12	Delay of mobilization of resources	✓	✓	✓
13	Lack of cash flow			✓

IX . RISK RESPONSE MONITORING AND CONTROL

Risk Monitoring is a process that ensures that the identified risks are taken into consideration for their proper disposal. In other words, it's a process of developing alternatives to increase the opportunities and to reduce the threats to the project objectives. After completing the process of identifying, analysing and prioritising the risks a risk response can be developed to avoid the risks. The basic process involves to identify assign risk owners to take responsibility for the risks identified. It basically addresses risks based on their ranking or priority (PMBOK). A risk response plan is created as in Table X

Risk monitoring and control is the last step in the risk management process. It takes place throughout the life cycle of the project. As the project proceeds through various stages new risks come into being. Proper risk monitoring is required for identifying risks from time to time. This also helps in anticipating risks well in advance. Proper communication with all stakeholders is required for the periodical assessment of risks. The risk owners should keep the project manager informed from time to time about the effectiveness of the plan.

X . CONCLUSIONS AND RECOMMENDATIONS

Since risks from external sources are the most critical ones and due to the fact that they are beyond the control of the project, appropriate risk transfer strategies have to be given more importance. Risk management plan should be started off early in the project conception stage and its activities should be carried out throughout the course of the project. Moreover, secondary and residual risks should be identified from time to time and they should be updated in the risk register. Another important principle that should be kept in mind during risk management is that the cost of mitigating or avoiding the risk should not be greater than the cost of the risk itself.

Some recommendations for future research include quantitative analysis of the risk identified and verifying the validity of the model. In this study only a qualitative analysis was done, so it can be used as an aid for a quantitative analysis of risks in tunneling. Due various constraints the validity of the proposed model was not checked. A proposal can be put forward for verifying the validity of the model. This concept is generic and hence we can extend this concept to fields other than tunnelling such as hydropower, bridges, nuclear and power plants.

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