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Project management study on metro tunneling project- A case study on BKC metro project

Arnab Sarkar
arnab.sarkar.2019@nitie.ac.in
National Institute of Industrial Engineering, Mumbai, Maharashtra

B. K. R. Naik
dr.bkrnaik@nitie.ac.in
National Institute of Industrial Engineering, Mumbai, Maharashtra

V. B. Khanapuri
vbkhanapuri@nitie.ac.in
National Institute of Industrial Engineering, Mumbai, Maharashtra

ABSTRACT

The primary aim of the study was to identify the risks involved in the "Line-III" of the metro project in Mumbai. A comprehensive evaluation was done based on a literature review of similar projects, government reports and finally site visit including a comprehensive interview of several teams. Some of the biggest risks include land acquisition, seasonal problems (monsoon), the safety of nearby buildings, manpower allocation. Thorough analysis and interview helped in identifying sixteen risks in total and then they were subjected to Risk Break Down structure where each of the risks was categorized and its impact and likelihood were determined. Then all of the identified risks were subjected to Impact-Likelihood matrix and risk register were developed. Primarily four risks that is Clearance from nearby buildings (PAP), Geological Changes in specific radius of the project, Drainage/ Waterlogging, Fire hazard were lying in the red zone of the matrix which suggests that these were the risk that needs proper mitigating strategies first followed by other risks. Diamond analysis of the project based on interviews showed in terms of "novelty" the project could be termed "platform" as new technology like NATBM (New Australian Tunnel Boring Machine) was used but no radical technology was used in the project, in terms of "technology" it was "high-tech", in terms of "complexity" it could be termed as "systems" as the project involved unique challenges which were resolved by some adaptive approaches, for "pace" the project was "time-critical" as any delay in the overall completion of the project would have resulted in overall increase in cost. Interviews were taken first to identify the risks associated with the project and then to find out the quantitative nature of each question. Thematic analysis of the interview was done and eight prominent themes were identified and then they were subjected to analysis. Scale wise analysis of the questions was done to quantify the qualitative approach of interviews. Overall the project was an innovative one where several risks were involved and there were properly mitigated/ transferred. New technology was used to overcome the unique risks associated with the underground tunneling process. Safety was given top priority in the site as well as the execution approaches used in the project.

Keywords— *Tunneling, NTCP, Thematic analysis, Risk breakdown structure, Impact-likelihood matrix, Risk register*

1. INTRODUCTION

Tunnels were one type of sub-structures that were built to aid in transportation or movement of materials [15]. Tunnels were quite different as compared to other structures as; the total load was based on assumptions and past experiences, overall safety cannot be properly gazed [10]. Generally to know more about the soil and rock boreholes were used to collect samples which were later tested in the geo-technological lab to find out the index properties of the soil/rock [11].

Type of tunneling and mechanisms were primarily governed by the ground conditions hence ground conditions play an important role in construction techniques. The total stress acting on the walls of the tunnels were due to the bulk weight of the rocks/ soils above it and the depth of the construction [11]. In certain cases, it was seen that the ground conditions were not fit for construction of tunneling and for that purpose the conditions were improved to stabilize the ground conditions [15].

Depth of the tunnel from the ground level plays a vital role in construction as well as the displacements transmitted to the surface. The smaller cross-section was more stable and to accompany the requirement for bigger cross-section without jeopardizing the stability designers generally opted for twin tunnels [25]. In modern day tunnel construction, various types of TBM (Tunnel Boring Machines) were used and to the line, the portion excavated RCC (Steel Reinforced Concrete) or fiber reinforced concrete was used. Waterproofing was important in tunnel lining construction to prevent excessive water flow into the tunnel. Ground movements were not a problem except in squeezing where the displacement was propagated due to the less cover that was given [27].

Though tunneling was considered to be one of the eco-friendly ways of proving transportation the construction risks associated were quite high [26]. Safety hazard while construction, as well as the acceptance of the tunnel after fire or flooding, was a major issue faced in various parts of the world [18]. One of the primary

fear was the fear of collapse, those affected by a collapse generally include the client who suffers financial loss, those building the tunnel who were at risk of death or injury and the public who may also be at risk of death or injury. Spectacular tunnel collapses, such as that at Heathrow in 1994 in the UK (HSE 2000) [7].

Mumbai Metro "Line-III" was a tunneling metro project (first in Mumbai) which was very complex in nature and included tunneling under a river [17]. The project faced several challenges from environmental clearances to managerial challenges [16].

2. LITERATURE REVIEW

The metro project was a part of the effort by the government to combat the problem of traffic and enhance the transportation infrastructure in India. Major cities in India were facing rapid urbanization and as a result traffic jam and pollution have become a major source of discussion and debate. As a result, some were focusing on public transportation systems such as Metro. Integration of these systems would increase efficiency and would become a key factor in increasing public transit usage as studied by Patil. K. et al. 2018 [30].

A study by Paulsson. A. et al. 2018, over the public transport planning, gave an insight into the collaboration between various levels of authorities in the planning of public transport. Based on the interviews, it was concluded that generally Regional Authorities plan the requirement of the system with the local bodies and basic design drafts were finalized then the Central government comes into the mix. One of the advantages of this was collaboration hinge on the ability to coordinate actors to put in place processes where the feasibility of plans could be established, and where a sense of common identity could be constructed [31].

As per the study of Shan. L. et al. 2017, there was a clear difference in culture, economy, and morphology between the urban and the rural population. Authors summarized the different types of conflicts that may arise during land acquisition such as property conflict, resource conflict and development conflict. Cases of property conflict, which arises during land acquisition and expropriation. Resource conflict was due to pollution, resource constraint and development conflict were due to improper distribution of schemes from the government, policy structure. From the paper, it was evident that the land acquisition was a challenge but the place, demographics and the macro-economic of that area plays an important factor and should be dealt with accordingly [32].

Comparative analysis between Superstructure and Substructure was done to understand the design, construction, maintenance and risks [10]. Research papers, Journals, Books were studied to identify the parameters [11].

High energy consumption, high Greenhouse Gas (GHG) emission and high resource consumption were some of the characteristics of tunnel construction. Tunnelling was highly dependent upon the surrounding rocks. A study by Jianfeng. X. et al. 2018, found that the emission increment occurs sharply in many cases after comparing the same construction for different surrounding rock conditions [29].

Hoover dam study by Kwak. Y. et al. 2013, gave a brief idea about the various types of challenges one faces during the construction of a complex project and how innovative approaches were adopted to overcome the challenges [16].
Maintenance and monitoring of tunnel were important for the safety and research by Qin. S, et. al. on "Application of magnetic resonance sounding to tunnels for advanced detection of water-related disasters", where modern techniques were used to detect the fault. Cavities occur unpredictably in the tunnel, and well-developed karst conduits were frequently encountered which resulted in safety problems, such as water gushing and rapid flooding [35].

Seike. M. study on "Evacuation speed in a full-scale darkened tunnel filled with smoke" gives a broader aspect of emergency evacuation in case of fire [23]. Tunnel fire created dense black smoke that covers ceiling lights and darkens tunnel spaces. Based on the human tendency to walk in dark, smoke and panicked state were taken into account to calculate the average speed and safety recommendations [31].

Maintaining the safety of the tunnel during the construction phase was very challenging as in the case of Laodongshan Tunnel in China. Cao. C. et al. 2018, studied the Squeezing failure of the tunnel and factors leading to the failure. Some of the important factors leading to tunnel failure were high in situ stress, soft-weak rock, groundwater seepage, weak support, delay closure of primary support, etc. Some of the recommendations and counter measures were proposed during construction, including strengthened pre-support, improvement of support stiffness, grouting reinforcement, installing additional supports, closing the tunnel ring early, and timely installation of secondary lining [31].

Another failure study was done upon the Liziping Tunnel located in the south-western mountainous area of China. Majority of the support structured failed after completion. Authors analysed the stress developed and used a simulation technique to predict the failure [24].

Modern day projects were not static, scope and final objective could deviate and these scenarios were analysed by Mehta. C Et al 2016 in his study [36]. The author studied the project management scenarios with a diamond framework (N- Novelty, T- Technology, C- Complexity, and P- Pace). Project parameters were classified, differentiated and framework was used to give the final overview of the project [37].

- **Novelty:** How crucial new aspects of the project are (New Creations)
- **Technology**: Use of new technology if any (Technological Difficulty)
- **Complexity**: Measure of how complex the project is (Measuring the Complications)
- **Pace**: How urgent the project is required to be completed. (Sense of Urgency)

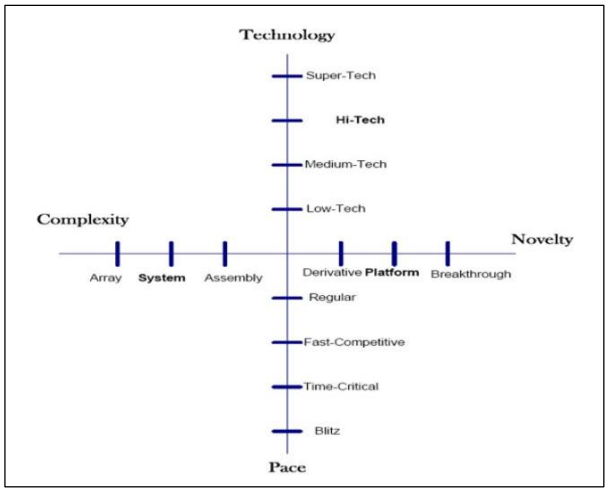

Fig. 1: The diamond model [37]

3. RESEARCH GAP AND OBJECTIVE

After analyzing the secondary data and available reports it was found that the Risk identification and mitigation were not properly done. Risk Breakdown Structure was not prepared and integrated with the Work Breakdown Structure. The risk could have been further classified on the basis of impact and probability and Excel-based model for risk impact matrix could be developed [36].

The primary objective was to analyze the BKC underground tunneling project, identify the risks involved in the underground construction (tunneling) and study the innovative approaches used to mitigate the challenges [7], then to develop a Risk Register by identifying all the risks associated with the project and associate the Risk Breakdown Structure with Work Breakdown Structure and finally on the basis of that to identifying the various aspects of the project based on the NTCP parameters (Novelty, Technology, Complexity, Pace) [37].

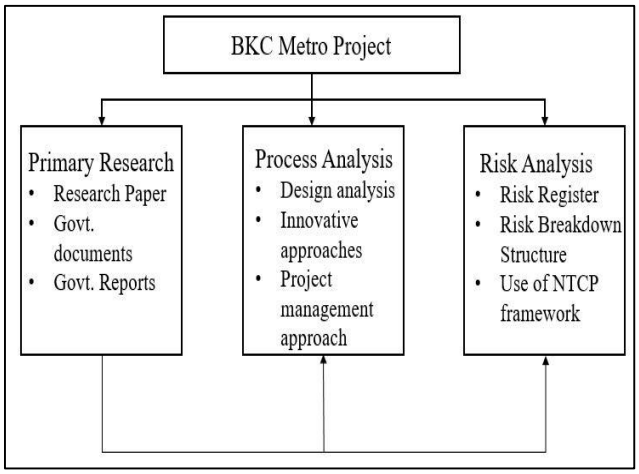

Fig. 2: Study objective

Further analysis of the project and its several parameters such as:

3.1 Design

The total process of designing of BKC metro project [1]. Studying whether any innovative approaches were taken by the engineers/ architect or not and to study the strategies adopted to overcome the constraints of the project [14].

3.2 Finance

To analyze the financial aspect of the project and weather SPV was present and how the investments were made [14]. Whether the investment came in stages or not, how all the risks were mitigated and whether general risk mitigating strategies like Turnkey contract, BOT, BOOT was used or not [13].

3.3 Risk management

For any large project, there was a certain risk that was associated with it [9]. Like in the case of the Underground City of Montreol the main challenge was the acceptance and in case of the Gotthard Base tunnel the complexity of the project like drainage, ventilation, fault lines, geological factors. Similarly, for the BKC metro project what were the major risk issues and how it is mitigated [28]

3.4 Project management aspect

In case of any complex project to avoid delays, project management becomes an integral part. To study the implementation of project management in various stages of the metro project and its benefits [36].

3.5 Innovation

Every project has a certain problem which needs a unique solution like Hoover dam project required pipe carrying cold water to cool and cure concrete, similarly in case of Gotthard Base tunnel to avoid water seepage Rubber Latex layer was put and then concreting was done over it [16]. Similarly, to study the problems faced by the BKC metro project and how it was dealt with [27].

4. METHODOLOGY

The primary research was exploratory in nature and was done by collecting reports, books, articles and government documents that captured various aspects of the Mumbai metro "Line-III" [12]. Based on the collected materials, authors were able to map out the design, economic, political, managerial, social, environmental and innovative approaches (if used) related to the project as studied by Kwak. Young. et al. 2013 [16].

After the initial research, site investigation of the actual project site was done to understand the actual condition of the construction. The site investigation was divided into three stages as suggested by Chapman. D in the book "Introduction to Tunnel Construction":

4.1 Preliminary investigation

The aim of this phase was to analyze the project and determine the overall scope of the project, risk, safety and other strategies that may be applied.

4.2 Design investigation

To look through the design process, delays associated with it and how the design partners aligned with the project.

4.3 Control investigation

Risk mitigating strategies, safety processes, NOC's etc.

After the completion of the studies, the findings were subjected to Thematic Analysis as suggested in the study by Thomas. J. Et al. 2008. The thematic analysis gave a broader perspective about the strategies and the methodologies of the project and how this project was different from other tunneling projects [18].

One portion of the metro that is from BKC to Dharavi would be under Mithi water stream and that was one of the biggest challenges for the construction company. The aim would be to identify the general risk for this kind of project as studied by Wang. X. et al. 2008 in his paper "Design of hazard prevention system for Shanghai Yangtze River Tunnel", unique risks that the company was facing and the strategies adopted to overcome the problem [17]. Regular site visits helped in pointing out several major risks associated with the project [7].

The last stage was to identify the risks, document risk register and RBS (Risk Breakdown Structure) [31]. Then to analyze the technology used in the construction and use NTCP (Novelty, Technology, Complexity and Pace) framework for each stage of the tunneling operations [36].

5. RISKS

Based on the interviews, government documents [12], reports [22] and site visits it was imminent that the project risk could be divided into three stages namely; project initiation, project execution and project monitoring [10].

5.1 Project initiation

One of the primary risks was land acquisition and clearance from the environmental board [32]. In many cases, buildings didn't allow MMRC to tunnel underneath them and as a result whole design needed to be revamped. This led to delays in the planning

stage and an increase in the overall cost of the project [19]. Seasonal delays also needed to be kept into account as monsoon resulted in delays in the project. Project planning and delays in clearance from the various department was a major issue as this was a Greenfield project. Forced Majeure like political instability, the earthquake that cannot be predicted and required special mitigating strategies [27].

5.2 Project execution

Manpower planning was a critical aspect in the project and proper allocation, availability of manpower along with heavy machinery was important to avoid any delays [13]. As the project was carried out in the residential area, the maximum noise level in the site was limited to fifty decibels, due to this during the night only excavation work (filling pit with soil), bar bending, steel fabrication was carried out. Site work which emits noise such as pile driving was restricted to only daytime [19].

There were several reports of settlements and water seepage into the nearby buildings [10]. To overcome this problem a team of geotechnical engineers were present and though out the premises of the site settlement determining instruments were laid to measure the settlement and in case if the settlement was more than the permissible limit than anchorage was used [24].

Anchorage was used to avoid the transmission of shock waves [11]. These walls were built up to the solid base layer. In case seepage grouting of pumable concrete was done to fill up the gaps and stop the percolation of water into the nearby buildings. The technical term used for these buildings was Project Affected People (PAP) [7].

5.3 Project monitoring

Safety of the project was very important and it was mandatory to wear a helmet, vest and boots in the site. Availability of medical area and prober barricading was done to avoid any undesirable accidents [25]. Regular assessment of the quality of the work was measured by the dedicated quality team present in the site [19].

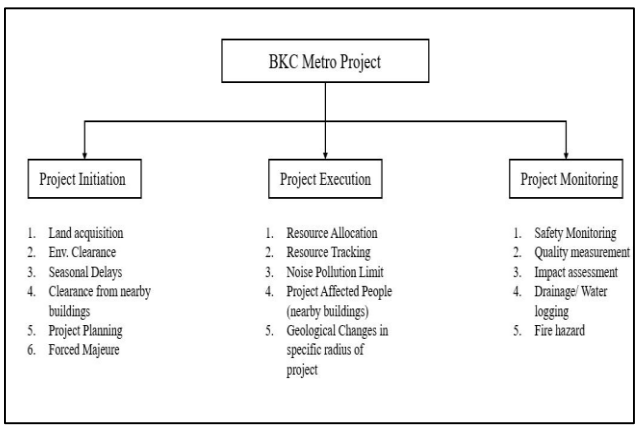

Fig. 3: Risk breakdown structure

6. CHALLENGES

The overall metro project was a complex process and lots of parallel processes needed to be handled simultaneously [14]. One of the important aspects was to keep the cost and time of the project in check. One of the primary examples was the allowance of the new kind of Tunnel Boring Machine (TBM) that is. New Austrian Tunnelling Method [11].

NATM was a method which uses the inheritance property of the rock to stabilize the tunnel. To overcome the risk associated with single package contract was divided into seven sub- packages [10].

TBM selection and contract evaluation was another managerial challenge and some of the processes that were implemented were [21]:

- An integrated approach to design approval
- Re-iterative design review process as more geotechnical data became available
- Collaborative debates and discussions

Another managerial aspect was the efficient system of ticket issue and fare collection [22]. To obtain the main aim of efficient, easy to operate/ maintain, automatic fares system a centralized system of ticketing was planned to be introduced [19].

On the basis of the surveys conducted by RITES, it was found that One thousand five hundred families would be affected and needed rehabilitation. Managing the families for proper rehabilitation and relocation was a major challenge for the project managers [19].

Safety of the workers in tunnelling project was important and for that, proper safety guidelines and mechanisms needed to be drafted in the site which would include planning for barricading, hoardings, signboards, traffic diversions [25].

To check the impact of the project on the environment, water samples were taken from six locations. Then the sample was checked to measure the chemical and physical parameters. Water from the Mithi River had more chlorine content, was very hard and contained more than permissible levels of dissolved solids. Thus it was inferred that the water required treatment before domestic use. Out of the four groundwater sample taken three were within permissible limit and only require filtration and disinfection [22].

In order to compare the air quality Ambient Air Quality Monitoring required to be measured for all the construction sites [22]. Air quality monitoring was done at five stations that is. Grant Road, Churchgate, Mumbai University, Mahim, SEEPZ and Sahar Road for the measurement of some parameters like SPM, RSPM, CO, HC, SO_2 and NO_x. Based on the results it was inferred that the SPM(Suspended Particulate Matter) and RSPM (Respirable Suspended Particulate Matter) were higher than the NAAQ standards while components like CO, NO_x and SO_2 were within the limits suggested by them [19].

The noise pollution assessment of six sites found that all of them were under the permissible limit and proper scrutinizing helped in discovering the fact that the primary source of the noise was from the vehicular movement in the construction sites [22].VII.

7. RESULTS

Interview of personnel belonging to different departments was taken to get an overview of the project and project risks associated with it. Based on the responses received thematic analysis, quantitative analysis, NTCP and risk register was prepared.

7.1 Thematic analysis

Responses gathered for the four questions were used to determine the important themes, eight important themes were found out and considered for the analysis [18].

Themes identified were;

(a) Initial Risk is considered
(b) Risk in terms of Quality, Safety, Time
(c) Use of Project Life Cycle
(d) Risk Reduction and Mitigation

(e) Use of Qualitative Risk Assessment Methods
(f) Use of Quantitative Risk Assessment
(g) Consideration of Risk in the project
(h) Innovative Approaches Used

Table 1: Thematic analysis

Themes	Positive Response	Negative Response
Initial Risk is considered	6	-
Risk in terms of Quality, Safety, Time	3	3
Use of Project Life Cycle	2	4
Risk Reduction and Mitigation	1	5
Use of Qualitative Risk Assessment Methods	4	2
Use of Quantitative Risk Assessment	5	1
Consideration of Risk in the project	6	-
Innovative Approaches Used	6	-

The analysis of the responses found out that a hundred percent of the time it was believed that initial risk was considered for the project initiation. The risk was either considered in terms of time, safety, financial aspect or the whole life cycle of the project was considered and then risk in each phase was identified and mitigating strategies associated with each were adopted.

The risks which were identified may be subjected to qualitative analysis, quantitative analysis or both and it primarily depended upon the risk and its impact. It was found that most of the time risk was subjected to qualitative analysis to find out more about the risk and quantitative analysis to find out the actual numerical impact of the risk on the project. As this was a project of underground tunneling, a new type of challenges emerged and as a result, innovative approaches were used to overcome the problems.

7.2 NTCP analysis

The first step was to understand the whole project by analyzing government tenders and project details [19]. Then the whole project needed to be classified on the basis of Novelty, Complexity, Technology and Pace of the project [37]. A proper questionnaire was prepared and followed by an analysis of the responses [36].

It was found that in terms of "novelty" the project was "platform" in nature that is new methods were developed only for this project such as the use of NATBM for tunneling and anchorage walls to absorb the shock wave. Some of the technology was already present but their use was unique as this project posed some rare difficulties which were different from other projects.

With respect to "technology", the project was "high-tech" where some of the presently available technologies had to be modified and used to overcome the unique difficulties posed by the project.

In terms of "complexity", the project was "system" in nature that is due to the lack of innovation of new technology the risks were lower and parameters such as tunneling and lining were independent in nature.

It was concluded that with respect to "pace" the project was "time-critical" in nature where time was an important aspect of the project and any kind of delays was leading to monetary losses. To avoid this problem all the risk aspects like proper planning, material handling, and monsoon delays were taken into consideration during the initial phase.

Table 2: NTCP analysis and outcome

Parameters	Avg. Response	Outcome
Novelty	2	Platform
Technology	3	High-tech
Complexity	2	System
Pace	3	Time-Critical

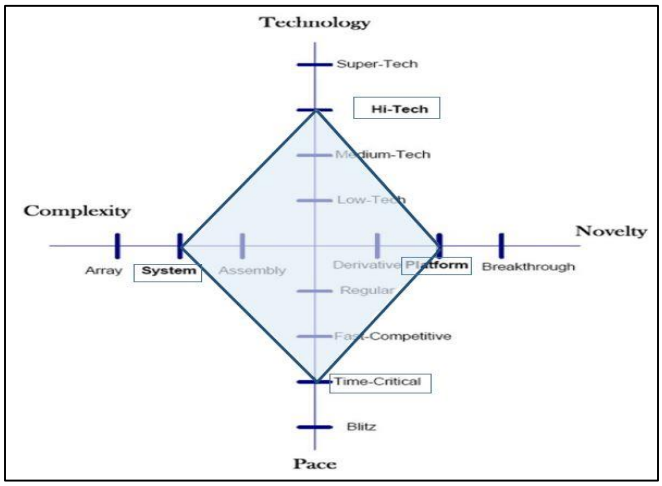

Fig. 4: NTCP result

7.3 Risk impact assessment

Based on the detailed interviews of personnel's belonging to different department project was divided into three stages
(a) Project Initiation
(b) Project Execution
(c) Project Monitoring

A total of sixteen risks were identified and it was mapped in impact – likelihood matrix based on the responses given by the project professionals.

A total of four risks lied in the red region of the impact-likelihood matrix and all of them required proper mitigating strategies.

The first one the Clearance from nearby building or Project Affected People (PAP) was a very important aspect for tunneling project. Without proper clearance, the whole project might come to a halt.

The second one was the risk of waterlogging/ drainage problem. If proper drainage was not maintained then there would be waterlogging in the monsoon season as this was a construction project below the ground level.

The third one was the risk due to fire hazard. As the project was underground thus the safety of the construction workers were very important and these risks need to be mitigated by installing fire safety measure and drills.

The fourth one was the Geological Changes in a specific radius of the project. This was the changes in the structural integrity of nearby buildings due to the project. To overcome this problem geotechnical team installed sensors to measure the shock transmitted to nearby buildings, their settlement and water seepage if any [11].

Table 3: Risk register

S no.	Risk	Impact	Likelihood
1.	Land acquisition	3	4
2.	Environmental Clearance	2	4
3.	Seasonal Delays	3	4
4.	Clearance from nearby buildings (PAP)	4	4
5.	Project Planning	3	4
6.	Forced Majeure	2	4
7.	Resource Allocation	3	3
8.	Resource Tracking	3	4
9.	Noise Pollution Limit	3	3
10.	Project Affected People	2	3
11.	Geological Changes in specific radius of project	3	5
12.	Safety Monitoring	3	5
13.	Quality measurement	3	4
14.	Impact assessment	3	4
15.	Drainage/ Water logging	4	4
16.	Fire hazard	4	4

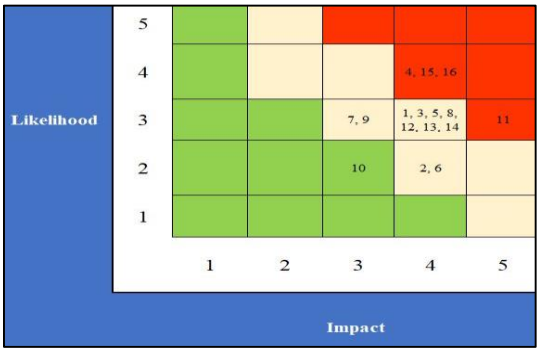

Fig. 5: Impact-Likelihood matrix

7.4 Quantitative analysis of risks

There was an interview conducted to know more about the project, project risks, mitigating strategies and innovating strategies used in the project. After the initial interviews risk assessment was done and the second set of questionnaire was prepared to quantify the process of risk assessment. A questionnaire of rating zero to five was used and four important questions were identified for quantifying the process. Responses of six personnel's were collected and analyzed.

Table 4: Quantitative risk assessment

Risk	Average Response	Significance
Is risk being considered for the project?	4.5	Certainly done
Is the analysis of Risks done properly?	3.83	Most of the time it is done
Is the use of Quantitative/Qualitative Methods done to avert risks?	4	Most of the time it is done
Is the use of Modern technology used to avert risks?	4.17	Most of the time it is done

It was found that ninety percent of the time it was believed that the risk was considered in the project which may be included in the project life cycle or in various stages of the project. Seventy-five percent of the time it was seen that the risk was mitigated properly. This was because as there were several contractors, subcontractors that sometimes the guidelines associated with each firm may contradict with other, leading to discrepancies [37].

Both quantitative and qualitative approaches were used to determine the risk, primarily risk register and CPM/PERT was used to quantify the risk. Modern techniques and innovating methods were used in order to avert risks.

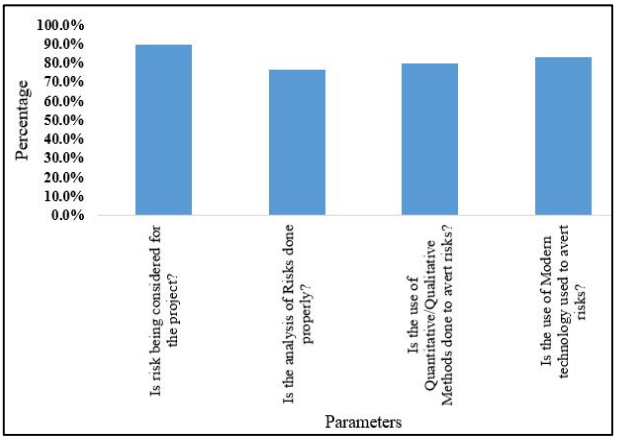

Fig. 6: Analysis of quantitative assessment

8. CONCLUSION

The primary motive of this study was to understand the various aspects of the BKC metro tunnelling project. Being an underground tunnelling project this had its unique challenges and required some innovative approaches to overcome those problems. First, the step was to look through the government documents, tender and get an overview of the project. Various government tenders and reports were instructed thoroughly and the preliminary objective was laid down. The main objective was to cover any gaps from the documents, studies and reports currently available for this project. A systematic approach of interviews, surveys and analysis were laid down to fulfil the objective.

Interview responses were taken, eight major themes were identified and analysis of the responses found out that a hundred percent of the time it was believed that initial risk was considered for the project initiation. It was found that most of the time risk was subjected to qualitative analysis to find out more about the risk and quantitative analysis to find out the actual numerical impact of the risk on the project. As this was a project of underground tunnelling, a new type of challenges emerged and as a result, innovative approaches were used to overcome the problems.

The next step was to conduct an NTCP (Novelty, Technology, Complexity, Pace) analysis where a proper questionnaire was prepared followed by the analysis of responses. It was found that in term of "novelty" the project was "platform" in nature that is new methods were developed only for this project such as the use of NATBM for tunnelling and anchorage walls to absorb the shock wave. The project was "high-tech" in nature where some of the presently available technologies had to be modified and used to overcome the unique difficulties posed by the project. In terms of "complexity", the project was "system" in nature that is in this case due to the lack of innovation of new technology the risks were lower and parameters such as tunnelling and lining were independent in nature. It was concluded that with respect to "pace" the project was "time-critical" in nature where time was an important aspect of the project and any kind of delay would lead to monetary losses. Thus from the NTCP analysis authors concluded that the project was platform, high-tech, system and time-critical in nature.

Through interview and site visits helped in identifying sixteen critical risks associated with the project. After the identification

of risks, the questionnaire was prepared to know the average impact and likelihood of each risk. Based on the responses four risks were lying in the red zone of the impact-likelihood matrix that is clearance from nearby buildings, drainage/ water logging, fire hazard and geological changes in specific radius of the project.

Quantitative analysis of risk was done where a questionnaire of rating zero to five was used and four important questions were identified for quantifying the process. It was found that ninety percent of the time it was believed that the risk was being considered in the project which may be included in the project life cycle or in various stages of the project. Seventy-five percent of the time it was seen that the risks were mitigated properly. Both quantitative and qualitative approaches were used to determine the risk, primarily risk register and CPM/PERT was used to quantify the risk. Modern techniques and innovating methods were used in order to avert risks.

Overall the project could be termed as unique in nature where various innovative techniques and methodologies were used to overcome the problem. Safety was given top priority in the site as well as the execution approaches used in the project. Safety and structural integrity of nearby building were also given proper importance.

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