Risk Based Building Information Modeling (BIM) for Urban Infrastructure Transportation Project

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***Abstract*—**Building Information Modeling (BIM) is a holistic documentation process for operational visualization, design coordination, estimation and project scheduling. BIM software defines objects parametrically and it is a tool for virtual reality. Primary advantage of implementing BIM is the visual coordination of the building structure and systems such as Mechanical, Electrical and Plumbing (MEP) and it also identifies the possible conflicts between the building systems. This paper is an attempt to develop a risk based BIM model which would highlight the primary advantages of application of BIM pertaining to urban infrastructure transportation project. It has been observed that about 40% of the Architecture, Engineering and Construction (AEC) companies use BIM but primarily for their outsourced projects. Also, 65% of the respondents agree that BIM would be used quiet strongly for future construction projects in India. The 3D models developed with Revit 2015 software would reduce co-ordination problems amongst the architects, structural engineers, contractors and building service providers (MEP). Integration of risk management along with BIM would provide enhanced co-ordination, collaboration and high probability of successful completion of the complex infrastructure transportation project within stipulated time and cost frame.

***Keywords*—**Building information modeling (BIM), infrastructure transportation, project risk management, underground metro rail.

I. Introduction

BUILDING Information Modelling (BIM) is a process involving the generation and management of digital representations of physical and functional characteristics of building projects or infrastructure related projects. Building Information Models (BIMs) are files (often but not always in proprietary formats and containing proprietary data) which can be exchanged or networked to support decision-making about a project. Current BIM software is used by individuals, businesses and government agencies who plan, design, construct, operate and maintain diverse physical infrastructures, from water, wastewater, electricity, gas, refuse and communication utilities to roads, bridges and ports, from houses, apartments, schools, shops to offices, factories, warehouses, prisons, etc. [1]. Further, construction of complex infrastructure project like underground corridor for metro rail operations involves risks and uncertainties throughout all the phases starting from feasibility through execution and operation. These risks would result in huge time and cost overrun which would drastically reduce the project feasibility and profit margin. This paper is an attempt to develop an integrated building information modelling (BIM) and risk management model for an underground corridor metro rail project in India during its construction phase.

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II. Literature Review

BIM is the extensive process of developing and using a computer-generated model to simulate the phases of a construction project digitally. This technology includes simulation of planning, design, construction and operation of buildings and structures [2]. BIM can also be looked upon as a modeling technology that can produce, communicate and analyze building models. In the area of BIM, building models are characterized by components represented by digital objects that contain data regarding graphics, attributes and parametric rules that allow them to interact in an intelligent way. The components carry data that describes object-related behavior, which can be used for analysis such as quantity take-off, clash control, digital energy and performance testing [3]. Thus, BIM is an intelligent parametric representation of the building or structure from which data can be extracted and processed in order to generate information that can be used as a basis for facilitating decision-making.

According to [4], BIM represents real world elements such as walls, doors, and windows as three-dimensional (3D) objects. In addition to geometry details, other information can be attached to these objects including manufacturers, fire rating, schedule, and cost estimates. Another BIM advantage is the ease to insert, extract, update, or modify digital data by owners, clients, engineers, architects, contractors, suppliers, and building officials. 3D object-oriented CAD models can serve as communication between different phases of construction like: conceptual to design development to construction to operation & maintenance.

Sarkar et al. [5] stated that BIM is an intelligent model based process that provides insight for creating and managing building and infrastructure projects with faster speed, economy and quality. BIM helps in predicting building performance and also helps in reducing construction wastes. It can also reduce the adverse impact of construction and help to integrate analysis, simulation and visualization into workflow primarily to make informed decisions throughout the project life cycle. BIM can also be used as a tool for facility management. Further, [6] developed a model where BIM can be applied for real estate projects. The problems created due to the co-ordination of the various agencies working in the project and also due to improper resource deployment would result in huge time and cost overrun.

According to [7] and [8] project risks primarily comprises of schedule uncertainties and cost uncertainties. These risks would result in huge time and cost overrun which would ultimately reduce the probability of successful completion of the project within stipulated time and cost frame. Risk management can be carried out effectively by following the basic steps like risk identification, risk assessment, risk response planning and mitigation measures. For effective risk assessment, proper investigation and identification of the sources of risks need to be carried out by the risk management team. These risks can be assessed or measured in terms of likelihood, impact and consequences. The most appropriate way of dealing with the project risk is treating it as a function of likelihood and impact [Risk = f (likelihood, impact)] [8] and [9]. Finally, as risk is a component which cannot be eliminated, suitable risk mitigation measures are to be suggested which will enable to reduce the identified project risks [10]. Both the concepts of BIM and risk management need to be applied to develop the integrated model.

III. Case Study

The project considered for analysis is construction of an underground corridor for metro rail operations in a metro city of an emerging economic nation in South Asia. The scope of work is design and construction of an underground metro corridor with six underground stations and a twin tunnel system. The underground stations are referred to as ST_1, ST_2, …., ST_6. Here ST_6 is the terminal station equipped with an over-run tunnel. 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. Type of contract is Design Build Turnkey (DBT) where the principal contractor is required to design the underground corridor and execute it. The contract period is about five years (exclusively for execution). The feasibility phase of the project is an additional five years. The project cost for execution is about INR 18 billion. The major scope of the project includes about 3,00,000 cum of concreting, about 24,500 MT of structural steel struts, about 5000 nos steel piles installation, soil excavation about 1,09,000 cum and rock excavation about 2,15,000 cum.

IV. Case Analysis

The sample stretch considered for study comprises of a preceding tunnel (530m), station box (290m) and a succeeding tunnel (180m). The primary activities considered for this study would include Feasibility Analysis (A), Design (B), Technology selection (C), Traffic diversion (D), Utility diversion (E), Survey works (F), Soldier / King piles (G), Timber lagging (H), Soil excavation (I), Rock excavation (J), Fabrication and erection of construction decks (K), Fabrication and erection of steel struts (L), Rock anchor installation (M), Shotcreting & rock bolting (N), Subfloor drainage (O), Water proofing (P) Diaphragm wall construction (Q), Top down construction (R), Permanent structure (S), Mechanical / Electrical installations & services (T) and Backfilling & restoration works (U).

In order to analyze the use of Building Information Modeling (BIM) in the Indian infrastructure construction industry a survey was conducted web-based as well as manually. This survey targeted varied stake holders belonging to the Indian AEC Industry. These construction professionals represented a range of business sizes and disciplines from across the industry, including architecture, engineering, and surveying.

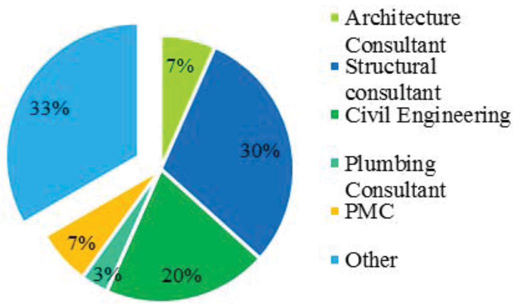

Fig. 1 Percentage of the various organizations who contributed for BIM survey

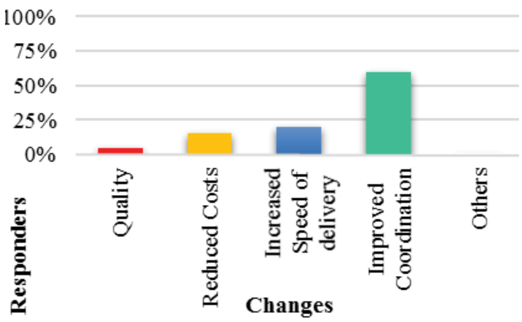

Fig. 2 Relative advantages of using BIM

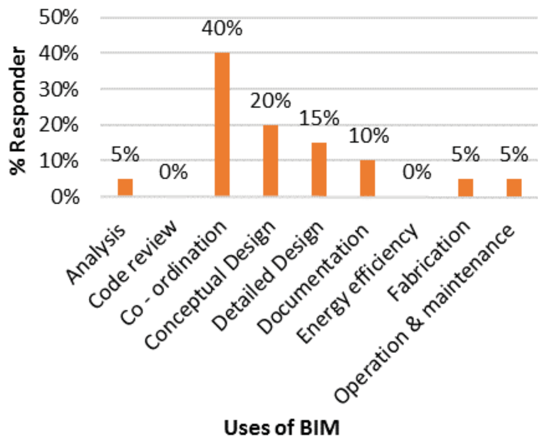

Fig. 3 Potential changes in a project due to usage of BIM

After conducting the survey, about 65 responses were obtained from respondents for various categories of attributes pertaining to BIM. The approximate percentage of the various categories of the organizations who contributed for the BIM survey work is presented in Fig. 1. Further, according to Fig. 2, the survey results shows that the future of BIM is quiet promising in terms of its applications in construction industry. About 5% users would use BIM for project analysis, about 40% for project co-ordination, about 20% for carrying out conceptual design, about 15% for carrying out detailed design, about10% for documentation, about 5% for fabrication related works and another 5% for operation and maintenance related works. It is also observed that none of the users would prefer BIM for the use of code reviews and energy efficiency related works. Finally, according to Fig. 3, the survey results about the potential changes which BIM can bring into a project are “quality” which is the opinion given by 10% of the respondents, “reduced costs” (given by 20% of the respondents), “increased speed of delivery” (24% of the respondents) and “improved co-ordination” (given by 60% of respondents).

The changes which usage of BIM can bring to a complex infrastructure project like construction of underground metro rail corridor would be in terms of improved co-ordination, better resource allocation and deployment, better quality management, equipment management, safety management and materials management. This would help in increasing the productivity of the project.

The risks identified under each activity of the underground corridor metro rail project have been listed and a detailed questionnaire consisting of all the identified risks as per the classification stated above have been framed. The detailed questionnaire consisting all of the identified risks as per the classification was circulated amongst about 70 experts having adequate experience in underground construction projects or similar infrastructure projects. These experts were required to respond about the likelihood of occurrence and the weightage associated with each risk as per their experience. The methodology for receiving the filled up questionnaire from the respondents were personal approach, telephonic conversation, e-mails and posts. The experts were Designers, Consultants, Dy. project leader, Project managers, Dy. project managers, CEOs, Managing directors, Area managers, Quality assurance / Quality control in-charges, Safety in-charges, Senior engineers and Project engineers of the principal contractor of the above project, client organization, consulting organization, major sub-contractors of the above project and other ongoing metro rail projects within the country. Of about 70 experts 50 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 Delphi technique. Some basic assumptions are considered during the analysis. These assumptions are (i) the maximum cost overrun permissible is 25 % of the basic cost beyond which the project becomes less feasible and (ii) the maximum permissible time overrun for infrastructure projects is about 30% to 50%.

A. Application of Expected Value Method (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 was 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 Fig. 1 have been analyzed at 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 III. Thus, as per the analysis, 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 30-50 % of the estimated base time. Exceeding these limits would increase 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 nearing the upper limit of permissible time overrun. Thus it is essential to judiciously follow the risk mitigation measures to ensure that the project is completed within scheduled time frame.

TABLE I
COMMON RISK SOURCES IN METRO RAIL PROJECT

Sr. 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	Unforseen 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

TABLE II
PROJECT EXPECTED COST AND TIME ANALYSIS FOR METRO RAIL PROJECT

Base Cost Estimate (INR Million)	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

Monte Carlo simulation has been applied to predict the outcome of the expected time (ET) and expected cost (EC) of all possible paths of activities as represented in the network diagram of the project. Monte Carlo simulation also takes into account the effects of near critical paths becoming critical. By carrying out detailed path analysis of the project network diagram, it is observed that path A-C-E-D-G-I-P-T has the longest duration of 3786 days and hence the critical path. The corresponding cost for completion of activities along this path is INR 1220 Million. It is also observed that the probability of successful completion of the project within 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 the probability of about 4.8% for successful completion within stipulated time and cost frame. There are all chances of this path becoming critical. Outcome of path analysis is presented in Tables IV and V.

TABLE III
DESCRIPTION OF THE MAJOR ACTIVITIES ALONG WITH THEIR RELATIONSHIPS

Activity	Description	Immediate Predecessors	Duration (Days)
A	Feasibility studies	-	1875
B	Design	A	295
C	Technology selection	A	90
D	Traffic diversion	B, E	475
E	Utility diversion	C	315
F	Survey works	B, E	290
G	Soldier / King piles	D	356
H	Timber lagging	C	240
I	Soil excavation	G, F, H	330
J	Rock excavation	L, R	165
K	Fabrication and erection of construction decks	C	170
L	Fabrication and erection of steel struts	C	690
M	Rock anchor installation	N, O	285
N	Shotcreting & rock bolting	L, R	120
O	Subfloor drainage	Q	170
P	Water proofing	I, K, J, M	120
Q	Diaphragm wall construction	C	145
R	Top down construction	Q	122
S	Permanent structure	N, O	570
T	Mechanical / Electrical installations & services	P, S	225
U	Backfilling & restoration works	N, O	225

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 to be critical. The corresponding cost for completion of all the activities along the critical path is INR 1222.8 Million. The probability of successful completion of path 2 or critical path within scheduled time is 50%. The probability of successful completion of the near critical path or path 1 within scheduled time is 84.13% (Z = 1.009, P = 0.8413). Also the probability of successful completion of all the paths with 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).

TABLE IV
MONTE CARLO SIMULATION FOR PROJECT TIME

Path	Activity / Path	Path duration (days)	Probability of Success
1	A-B-D-G-I-P-T	3676.17	4.8%
2	A-C-E-D-G-I-P-T	3785.98	4%
3	A-C-E-F-I-P-T	3244.88	6.6%
4	A-C-H-I-P-T	2879.88	8.2%
5	A-C-K-P-T	2479.67	10.6%
6	A-C-L-J-P-T	3164.79	6.5%
7	A-C-Q-R-J-P-T	2741.60	5.7%
8	A-C-Q-O-S-T	3074.89	11.2%
9	A-C-Q-O-U	2504.95	15.4%

TABLE V
MONTE CARLO SIMULATION FOR PROJECT COST

Path	Activity / Path	Cost (INR Million)	Probability of Success
1	A-B-D-G-I-P-T	1192.8	4.8%
2	A-C-E-D-G-I-P-T	1222.8	4%
3	A-C-E-F-I-P-T	961.7	6.6%
4	A-C-H-I-P-T	871.1	8.2%
5	A-C-K-P-T	820.9	10.6%
6	A-C-L-J-P-T	1081.9	6.5%
7	A-C-Q-R-J-P-T	922	5.7%
8	A-C-Q-O-S-T	1501	11.2%
9	A-C-Q-O-U	650.7	15.4%

Carrying out about 15,000 runs of Monte Carlo simulation, the EC was found to have a value of INR 3533.5 Million and the ET of the project was found to be 4352.22 days.

V. CONCLUSION

The present study shows that for an infrastructure transportation project like construction of an underground corridor metro rail project, during the construction phase, usage of BIM would reduce the co-ordination problems between various agencies involved in multidisciplinary work and thereby would enhance the collaboration project due to which many of the project risks can be avoided and also the overall project cost can be reduced. From detailed project risk management analyses, it can be concluded that for complex infrastructure projects like that of an underground corridor construction, 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. Thus about INR 0.82 Million per day per station would be incurred extra 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 per day have to be incurred extra by the project authorities. Thus the integrated approach would enable the project authorities about the potential cost savings through application of BIM and also be aware of the consequences particularly the prospective time and cost overrun if proper risk management is not followed.

As a future scope of study the BIM model can be further strengthened by exploring the potential of use of BIM with Integrated Project Delivery (IPD) for operation of the transportation system.

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