ESTABLISHING THE ROLE OF BIM TOWARDS MITIGATING CRITICAL PROJECT RISKS ASSESSED USING A FUZZY INFERENCE SYSTEM

Sulakshya Gaur[1] and Abhay Tawalare[2]

ABSTRACT

Risk management is an essential process for the successful execution of the project, and it is pertinent in achieving the project objectives and leading to its successful outcome. The nature of the construction industry, which is full of uncertainty and high capital investment, makes it notably more critical to address and manage the risks promptly. The most important part of the risk management process is identifying and assessing risks. However, the traditional Probability (P)-Impact (I) matrix used in their evaluation fails to account for the uncertainties witnessed in the determination of both P and I. This paper, therefore, uses a fuzzy approach to develop a risk assessment model. Further, the results of the generated model are compared with the conventional P-I matrix to show the effectiveness of the adopted fuzzy system. The data for the model development was collected from one of the metro-rail projects through a questionnaire. Subsequently, semi-structured interviews were conducted to identify the advantages of BIM in the project. The recognized BIM advantages were then correlated with the critical project risks to present it as the process for mitigating these risks. The study findings present the use of FIS to overcome the uncertainty in the risk management process, followed by the applicability of BIM as a risk mitigation tool. Establishing the role of BIM in the risk mitigation process can help in its wider acceptance in the construction industry.

Keywords: Building Information Modelling (BIM); Construction project; Fuzzy Inference System (FIS); Megaproject; Risk Management.

1. INTRODUCTION

The distinctive nature of construction projects which accounts for process complexity, involvement of multiple stakeholders, substantial capital investments, and other external factors, make it a highly risk-prone industry (Siraj and Fayek, 2019). Risk is defined as "an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objective." (PMI, 2017). If the adverse risks are not addressed timely and properly, it can lead to the problems of time and cost overrun (Wu, et al., 2018) along with the complete scrapping of the project in highly adverse conditions. Therefore, it

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[1] Ph.D. Scholar, Department of Civil Engineering, Visvesvaraya National Institute of Technology, Nagpur, Maharashtra, India. sulakshya@outlook.com
[2] Assistant Professor, Department of Civil Engineering, Visvesvaraya National Institute of Technology, Nagpur, Maharashtra, India. abhaytawalare@civ.vnit.ac.in

becomes essential that a thorough risk management approach be practiced in such projects that can lead to their successful execution.

The first and the essential part of the risk management process is their identification, followed by their assessment (Yazdani-Chamzini, 2014). This is particularly important to devise a risk response strategy efficiently. Although numerous studies have been done in the space for risk assessment, it is still heavily dominated by the adoption of a probability (P) and impact (I) matrix for their evaluation (Qazi and Dikmen, 2019). However, using the P-I matrix for risk assessment has its fair share of limitations. Its most critical limitation is handling the uncertainty around the estimation/determination of both probability and impact of the identified risk. Although the project expert can provide their opinion to model the uncertainty, it becomes difficult for them to quantify their knowledge to estimate that uncertainty (Yazdani-Chamzini, 2014). Also, obtaining the requisite accurate data for the efficient implementation of the methods is a complex and challenging task (Winch, 2010). Therefore, to overcome this, a suitable measure needs to be adopted that can efficiently employ linguistic terms to model the uncertainty witnessed for the process or a sub-process. Obtaining the information regarding the risk importance is important as it can help formulate a response strategy.

Creating a risk response strategy to cope with all the identified risks is generally difficult due to several reasons, such as the budget constraint, the existence of process risk factors under different sub-processes, and situational demands that require control over some process in a specific subprocess (Wu, et al., 2018). Therefore, to facilitate the process of risk mitigation, it becomes essential that new approaches be undertaken that can help overcome some of the critical challenges. The adoption of building information modeling (BIM), although not entirely, complements the strategies adopted for the mitigation of project risks. The improved design visualization, collaboration, and information exchange brought in by BIM (Gaur and Tawalare, 2022) in the projects help to overcome certain key risks witnessed in the projects. The risks account for project designs, frequent design changes (Luo, et al., 2019), government interventions, and risks related to information transfer and availability (Taylan, et al., 2014) can be efficiently dealt with by using BIM. The ability of BIM models to provide an improved level of collaboration (Jin, et al., 2017) followed by the swift relay of information (Ganbat, Chong and Liao, 2020) among the stakeholders can help in dealing/mitigating some of the critical project risks.

Therefore, the aim of this paper is two-fold. Firstly, it aims to provide a method for risk assessment that can cater to the uncertainties witnessed in estimating the probability and impact of risk. The second aim is to present the applicability of BIM as a tool in the risk mitigation process.

2.   LITERATURE REVIEW

The major challenge with developing an efficient risk assessment approach is to deal with the uncertainty (Wang, et al., 2012). The accurate assessment of the risks requires complete information regarding the consequence and the frequency of their occurrence (Jaderi, Ibrahim and Zahiri, 2019). However, achieving these is challenging due to a lack of knowledge, incompleteness, and inaccuracy in its measurement (Yaqiong, Man and Zhang, 2011). Moreover, obtaining the definite values for risk assessment can be highly resource-intensive and sometimes impossible due to the sheer uncertainty in its estimation (Urbina and Aoyama, 2017). Several methods like the alien eyes' risk model developed

by Wang, Dulaimi and Aguria (2004), the use of TOPSIS grey and grey numbers for risk assessment by Zavadskas, Turskis and Tamošaitiene (2010), combined fuzzy logic and AHP in construction project risk assessment by Mohammadi and Tavakolan (2013), etc. have been posited to assess project risks by overcoming the shortcomings of the conventional risk assessment process. Still, among them, fuzzy logic is considered the best approach for assessing the risks (Jaderi, Ibrahim and Zahiri, 2019). 'Fuzzy logic' is defined as a set of mathematical principles established to represent knowledge deriving its dependence on the degree of membership instead of classical binary logic (McBratney and Odeh, 1997, Grosan and Abraham, 2011). When dealing with the imprecision inherent in many problems, using a fuzzy membership function (MF) for risk will help cater to the ambiguity or uncertainty witnessed in the decision-making (Kumar and Maiti, 2012). Fuzzy logic considers the use of linguistic terms rather than the numerical values as the variables for the application in the fuzzy sets (Hatefi, Basiri and Tamošaitienė, 2019).

2.1 FUZZY INFERENCE SYSTEM (FIS)

The fuzzy inference system (FIS) is defined as receiving output based on the input through the use of fuzzy logic (Alidoosti, et al., 2012). An essential advantage of FIS is its ability to use linguistic terms to provide an inference framework for modeling complex problems. Several previous studies have used fuzzy logic to develop FIS to assess risks in varied projects. In the study conducted by Yazdani-Chamzini (2014), the authors developed and used a FIS to evaluate the risks associated with the tunneling project. Similarly, Jaderi, Ibrahim and Zahiri (2019) developed a fuzzy risk-based maintenance model that used the FIS for risk analysis in the petrochemical industry. The development of the FIS system is based on the essential formulation of If-Then rules. All the previous studies have used various numbers of if-then rules for developing the inference mechanism in the FIS. Therefore, devising the correct number of such rules and their accurate writing is integral to the FIS (Hatefi, Basiri and Tamošaitienė, 2019).

Although the use of FIS for the assessment of risk serves as an initial step toward the risk management process, specific strategies need to be developed to mitigate assessed risks. The improvement and enhancement of the communication between the stakeholders (Yang and Zou, 2014), followed by maintaining and encouraging close collaboration with the associated stakeholders (Goh and Loosemore, 2017), and the use of information technology tools to facilitate the additional requirement of coordination, and collaboration (Hwang, Shan and Looi, 2018) are some of the strategies that have been presented as the mitigation measures for various types of risks in previous works. However, achieving these independently is not easy as the mitigation process is highly resource-intensive and sometimes proves to be very costly. Therefore, to make the mitigation process efficient, BIM as a process needs to be looked into. The usage of BIM helps overcome certain risks by improving collaboration and relaying complete project information among the stakeholders. It also tends to have an implication on the overall efficiency of the projects.

The previous studies have independently looked into risk assessment and mitigation measures based on the above discussions. Although there have been established advantages of BIM, they need to be looked into in detail concerning their implications in the risk mitigation process. Moreover, the perceived benefits of using a fuzzy approach

to deal with the uncertainty in decision-making need to be extensively adopted in the risk assessment in construction projects.

3.   RESEARCH METHODOLOGY

The study adopted a combination of methods to identify and assess the risk and how the BIM favored their elimination or mitigation. Initially, a thorough systematic literature review was undertaken to determine various significant risks faced in the construction projects. This was followed by data collection to assess the influence of the identified risks. Data was collected by using a case study-based research methodology. A single case was selected because BIM is being utilized in the project. A metro project in one of the cities of Central India was selected as the single case for collecting the requisite data. The project has an estimated completion cost of US\$4.0 billion (30,000 crores) and has adopted the use of 3-D BIM with the LOD500 (level of development). Primary data was collected through expert interviews. Ten project participants from the design, planning, quality control, and safety departments were interviewed for the data collection process. Initially, the participants were presented with a questionnaire where they were asked to rate a particular risk on the 'level of their impacts to effect the project' and 'it is chance of occurrence/probability.' A five-point Likert scale was used to obtain their responses. The adopted scale for data collection is presented in Table 1 below. Column 2 in the below table shows the 5 levels of parameters classified to judge the impact and probability of a particular risk. Column 3 of the table shows the adopted scale having a crisp (i.e., a definite integer value) value in relation to the impact and probability parameters (linguistic) of risks mentioned in column 2. This was used to judge the risk influence level based on the conventional approach of the P-I matrix. Further, to account for the uncertainty witnessed in the human decision-making process, fuzzy ratings were developed and presented in column 4 of the table. Instead of adopting a definite integer value, Fuzzy rating takes a range to address the parameters of impact and probability. This range was obtained based on the adopted Gaussian membership function for the input values (i.e., impact and probability of risk) presented in Figure 1.

Table 1: Scale adopted for risk assessment

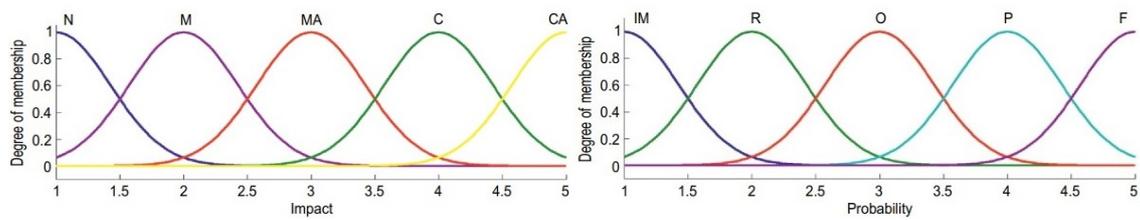| S.No. | Linguistic Scale | | Crisp Scale | Fuzzy Rating |
	Impact (I)	Probability (P)		
1	No Impact (Negligible)	Very Unlikely to Occur (1-10%)	1	$1 < (P, I) \leq 2.5$
2	Low Impact (Marginal)	Unlikely to Occur (11-40%)	2	$1 < (P, I) \leq 3.5$
3	Medium Impact (Moderate/Tolerable)	May occur about half of the time (41-60%)	3	$1.5 < (P, I) \leq 4.5$
4	High Impact (Critical)	Likely to occur several times (61-90%)	4	$2.5 < (P, I) \leq 5$
5	Very High Impact (Catastrophic)	Very likely (frequent) to occur (91-100%)	5	$3.5 < (P, I) \leq 5$

Figure 1: Adopted membership function for input variables

A dual approach based on the determination of risk Probability (P) - Impact (I) index and the risk assessment using a developed fuzzy model was adopted to assess the influence of identified risks. Since the quantification of expert knowledge is a difficult task, the fuzzy model was used to model the system's complexity through linguistic terms. Fuzzy logic can handle and express the ambiguity of human thinking and rationale into data that can be easily computed (Yazdani-Chamzini, 2014). Several FIS have been developed to model both the linear and non-linear behavior of the system. However, the Mamdani fuzzy model is the most popular mechanism for modeling problems related to uncertainty and complexity (Yazdani-Chamzini, 2014). There are various features associated with the Mamdani fuzzy model that makes it a preferred choice for dealing with complex problems (Wang, 1994): 1) the use of real-valued input and output makes it suitable for the engineering system, 2) A natural framework is made available for incorporating fuzzy *if-then* rules from experts, and 3) there are numerous choices and freedom to choose fuzzifier, inference engine and defuzzifier. The developed fuzzy inference system model (FIS) replaced the risk index with the risk assessment function and is presented in Figure 2.
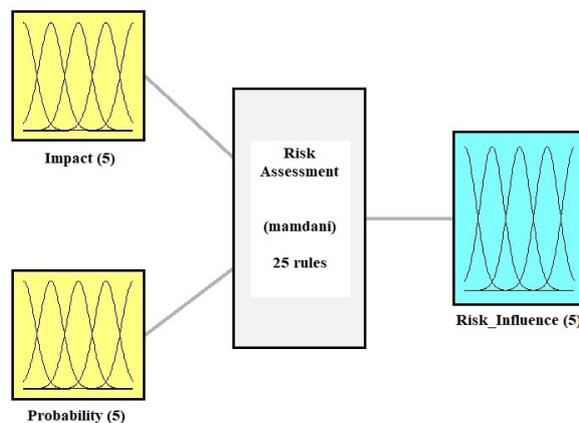

Figure 2: Structure of the used fuzzy model

The developed FIS model consists of four parts, i.e., fuzzification, knowledge base, inference engine, and defuzzification. The input and output relationship can be easily understood using a 3-dimensional plot, also known as a control surface. The developed FIS surface model is presented in Figure 3. The centroid method was used for defuzzifying the output in this study. The FIS model was developed and analyzed using MATLAB.
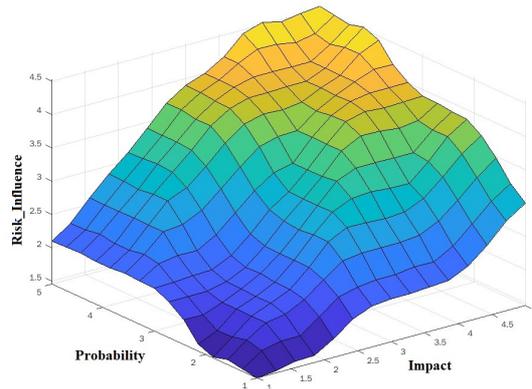
Figure 3: FIS surface diagram of the risks

The assessment of the risks was also done using the traditional P-I matrix, where the risk influence (R) was calculated as the product of P and I. Based on this calculation and the output of the FIS model, the risks were categorized into five categories. Their linguistic classification and the crisp scale and fuzzy scale (fuzzy output based on gaussian membership function) are presented in Table 2.

Table 2: Scale developed for determining the risk influence (Yazdani-Chamzini, 2014)

S.No.	Linguistic Scale	Crisp Scale (R = P X I)	Fuzzy Rating
1	Risk is Insignificant and can be tolerated without devising any mitigation measures	1 - 4	$0 < R \leq 2.5$
2	Risk is tolerable and requires partial mitigation measures	5 - 8	$0 < R \leq 3$
3	Risk influence is substantial and mitigation might be required	9 - 12	$1 < R \leq 4$
4	Risk is significant, and proper mitigation measures should be adopted to reduce the risk.	13 - 16	$2 < R \leq 5$
5	Risk is intolerable, and mitigation measures that reduce the impact of the risk should be adopted.	17 - 25	$3 < R \leq 5$

Further, the participants were asked questions about the advantages of BIM they witnessed during the project. This was achieved through the conduction of semi-structured interviews with the participants. The interview data were analyzed using NVivo 10. NVivo is a computer-assisted qualitative data analysis software used to code and analyses qualitative data. It analyses the data and helps in transcribing, storing, and cataloging these data. The advantages witnessed in the project and enumerated by the respondents were coded as nodes. These nodes were then categorized based on the percentage of articles coded for a particular BIM advantage. The % of articles coded was calculated based on the number of articles that cited a specific advantage over the total number of interviews conducted. The impact of these advantages was then correlated with the mitigation of certain critical risks witnessed in the project.

4.   RESULTS AND DISCUSSIONS

The influence of the identified risks was determined using both the P-I matrix and the FIS model. The risk influence through the traditional P-I matrix was calculated on the scale

of 1-25 and the FIS model on 0-5. The determined risk influence through both models is presented in Table 3.

Table 3: Influence of the Identified Project Risks

Risk	Risks	Risk Influence (P-I Matrix)	Rank	Risk Influence (FIS)	Rank
R1	Adverse impact on the Environment due to project.	9.99	13	3.25	13
R2	Project personnel unavailable due to external constraints	4.76	17	2.40	16
R3	Improper allocation of roles and responsibilities	8.25	15	3.06	14
R4	Improper document management and cataloguing	10.88	9	3.42	11
R5	Frequent design modification and improper designs	16.65	1	4.09	1
R6	Improper project scheduling and forecasting	13.94	4	3.88	5
R7	Inefficient planning and management of resources	13.53	5	3.76	6
R8	Inefficient and improper monitoring and management of project assets	10.2	12	3.42	11
R9	Poor project supervision	10.8	10	3.52	9
R10	Lack of planning of budget and cash flows	8.46	14	3.33	12
R11	Lack of provisions for site safety	12.6	6	3.60	7
R12	Lack of provisions to protect IPR	6.2	16	2.84	15
R13	Logistical issues in material and component delivery	10.5	11	3.52	9
R14	Inefficient decision-making process	15.91	3	4.07	2
R15	Unclear communication between project participants	16.28	2	3.97	4
R16	Poor quality control parameters and measures	11.44	8	3.50	10
R17	Tangled and lengthy approval process	16.28	2	4.01	3
R18	Unsatisfied external stakeholders	12.54	7	3.58	8

The developed FIS model aims to overcome the most critical shortcoming of the conventional P-I matrix. The P-I method ranks the risk at the same level of importance, having a varied set of P and I. This leads to the basic assumption of considering both probability and impact as equally important in the risk assessment through the conventional method. For instance, assume two different sets of risks having a value of 4, 2, and 2, 4. The traditional approach would provide the influence values as 8 and consider them equally important. However, in actual circumstances, the implications of both risks may be different. This is where the use of FIS provides a considerable difference. The FIS model accounts for the uncertainty computed based on the membership function.

For instance, the ranking of R4 and R8 through the conventional method comes out to be 9 and 12, respectively. However, through the FIS model, both the risks show an equal

influence level as an output of 3.42 and a ranking of 11. Also, the risks R15 and R17 were ranked in 2nd place by the conventional risk matrix and were ranked in 4th and 3rd place, respectively, through the FIS model. The individual parameters, i.e., P and I values for both these risks, were 3.7 and 4.4, which gave them an equal value of influence, but through the FIS model, it was found to be 3.97 (for R15) and 4.01 (for R17).

The results of the traditional risk assessment are also presented with the help of a risk P-I matrix in Figure 3, where the entire matrix was distributed in four quadrants. The four quadrants comprised 'high impact-low probability'; 'low impact-low probability'; 'low impact-high probability'; and 'high impact-high probability. The HI-HP quadrant of the risk matrix represents the 'significant' and 'intolerable risk' as categorized in Table 2. The 8 risks under the quadrant of HI-HP are considered to have a significant impact on the project and need to be addressed timely before leading to some undesirable consequences. Table 3 also shows a general agreement among the influence levels of these 8 risks based on their ranks from both the analysis methods. Although there is a slight variation in the ranks of these eight risks, they still constitute critical based on their influence levels calculated from the respective models.
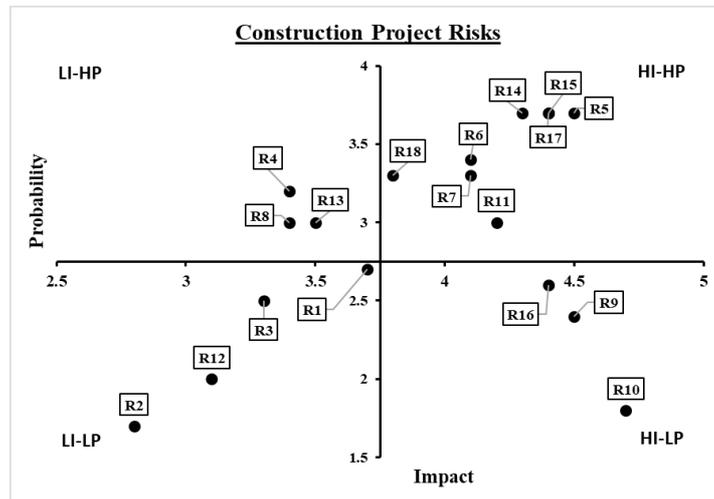

Figure 3: Risk P-I matrix

Once the critical risk was identified, the next step was to correlate them with the BIM advantages for suitable mitigation. The developed/incorporated mitigation measures here are presented as the advantages of BIM witnessed in the projects. The advantages coded in more than 50% of the interviews are only taken as mitigation measures and considered for subsequent discussions. These advantages are grouped under two constructs design optimization and efficient decision-making for the discussions.

4.1 EFFICIENT DECISION MAKING

This construct of the BIM advantages comprised 'better collaboration for obtaining coherent design solutions' as the most coded advantage (in 90% of interviews), followed by the 'ease in the communication of designs to approving authorities' (80%) and 'reduction in the number of change orders/RFIs' (60%). These advantages show the implication they can have in overcoming certain risks. For instance, the improved collaboration between the civil and systems contractors brings various designers and contractors on the same platform to obtain an optimized design solution. This helps

overcome the issue of frequent design changes at the later stage of the project, which is found to be an important risk in the works of Luo, et al. (2019). In this project specifically, the primary issue was efficiently managing the number of involved contractors and subcontractors. BIM allowed them to work together in tandem by analyzing their independent models with the complete project design by providing a digital workspace. The coming of civil contractors with the systems contract associated with installing HVAC systems and other essential utilities achieved the desired outcome in a specified time frame.

Improved collaboration and coordination between the stakeholders also help them relay complete project information. Apart from enhancing the collaboration between the stakeholders, the BIM models can efficiently store and share large chunks of data between the stakeholders. The digital storage and transfer of project data reduces the information loss from one stakeholder to another leading to the complete relay of information between them. The transfer of complete project information within the teams and groups is critical for improving the efficiency of any process (Taylan, et al., 2014). The improved project visualization, coupled with real-time data transmission among the participants, allows them to efficiently plan for the resources required in the project activities. The 3-D models, when integrated with the time, provide a better visualization to the management team to plan for the project's schedule. Moreover, the real-time information transmissibility provided by the BIM models conveys necessary information regarding the project schedule to the associated stakeholders, allowing them to suitably plan for further action.

The BIM models can convey the critical project data through the 3-D models. This eases the understanding of the project information and designs among the stakeholders. The most important implication of improved visualization through the developed BIM models is reflected in the communication of drawings to the approving authorities. This helps improve the efficiency of the approval process, which otherwise delays the design time and is an important risk in the work of Siraj and Fayek (2019). One of the reasons for this can be the approving authority's inability to comprehend project designs. A thorough understanding of such intricate designs can be time-consuming, making the whole approval process highly complex. The availability of the 3-D models, as opposed to the drawings, tend to improve this comprehension by providing visual cues. This facilitates understanding of the intricate details of the design through the generated models, leading to a reduction in the approval time. This improved understanding brought in by 3-D models also improves the communication with the external stakeholders if required. This can, in a way, keep them informed and content with the project, thereby improving their satisfaction levels with the project. Moreover the improved design visualization and better information transfer reduce the change orders or the request for information, leading to the mitigation of risk associated with the design modifications, which was found to be important in the works of Chatterjee, et al. (2018).

4.2 DESIGN OPTIMIZATION

This construct of BIM advantage consisted of clash detection as the most coded advantage (90%), reduced waste generation and better design visualization (both coded from 70% of the interviews). Clash detection refers to the identification and elimination of clashes between the building components during the design stage itself so that there is reduced or no rework during the execution stage. Clash detection is thought of as a subset of

improved collaboration. Bringing the various stakeholders together during the design stage allows them to look into multiple alternatives through the available 3-D models. This tends to improve coordination between them, which is an important risk in the work of Siraj and Fayek (2019). This enables them to identify any clashes in the models and designs beforehand. The most crucial benefit of prior clash detection is reducing the reworks during the project execution, which is found to be an integral part of design risk in the works of Chatterjee, et al. (2018).

The thorough clash detection between the designs improves the communication and collaboration between the stakeholder group. An efficient inter or intra-organizational information sharing is essential for maintaining operational efficiency in the event of joint operations (Keers and van Fenema, 2018). This was particularly important in the studied project because of the underground nature of the project. Since the project was completely underground, the placement of utilities in the cramped space was brought in by the efficient collaboration between the different contractors (civil and MEP contractors). A better design solution devoid of any clash also reduces the transfer of improper designs to the execution team during the project execution phase. Identifying and eliminating any clashes in the design stage can reduce or remove reworks in the project. This helps save construction costs and time on the ground of reworks and, most importantly, helps reduce the generation of construction wastes. The reduction in construction waste minimizes the project's impact on the environment, which serves as an essential impetus for improving the satisfaction of external stakeholders.

Identifying and visualizing clashes also enables the team to efficiently plan for on-site safety measures. For instance, the better information availability regarding the overhead utilities and equipment through the improved visualization brought in by the BIM models enables the team to place cautionary signs regarding the area to improve the safety at the project site. Moreover, the use of BIM models results in the generation of as-built models that also helps in conveying critical information about the built facility to the stakeholders, especially the O and M teams. This leads to improved decision-making during the O and M stage of the project.

5.   CONCLUSION

This study used the conventional risk assessment approach and the FIS model to evaluate the risks associated with a construction megaproject. Further, it presented BIM as a tool for mitigating certain key risks by establishing a correlation between its advantages and the witnessed risk. A discussion with an expert group from a metro-rail project was undertaken. The expert group was initially asked for their opinions on the probability and impact of the identified risks based on the developed linguistic scale. Subsequently, the obtained data were used in the fuzzy toolbox of MATLAB to create a FIS model for risk assessment. The obtained data were also analyzed using the crips values through the P-I matrix. A combination of both the employed methods served to compare the obtained results. The results favor the rigorous process employed by the fuzzy system to evaluate the risks. The most important advantage of this was witnessed when the risk had the same values of both P and I. The traditional matrix fails to differentiate or distinguish between the risk levels; however, the FIS model can differentiate between the influence levels of both the risks, thereby catering to the uncertainty around the determination of P and I value.

The risks were categorized under five categories i.e., insignificant, tolerable, substantial, significant, and intolerable, based on the influence levels. Through the results obtained from the P-I matrix and the FIS model, 8 risks belonging to the category of (HI-HP quadrant of the risk matrix) significant and intolerable were chosen as the critical risk, which needs specific mitigation measures. The mitigation measures were provided as the advantages of BIM, obtained from the interview conducted within the expert panel. The BIM advantages were classified under two significant constructs efficient decision making and design optimization. For instance, the collaboration among the stakeholders provided by BIM listed under the construct of efficient decision-making helps overcome the most critical risk, i.e., the frequent design modification and improper designs obtained through risk assessment methods. The findings of this work aim to overcome the uncertainty around the estimation of risk indexes and present BIM as an essential tool that can be used to mitigate key project risks. This helps present BIM as a critical process to improve the project's overall efficiency. It can, therefore, help in its wider adoption in the architectural, engineering, and construction (AEC) industry.

This work has a few limitations. First, since the research work used a retrospective case study of a metro rail project, the findings of this work need to be established by conducting similar studies on other types of projects. This will help ascertain the findings and the actual role of BIM along with the varied project types. Secondly, the identified risks are primarily focused on the design aspect of the project. Thus, there is a need to consider varied risk categories for establishing BIM as a tool for complete risk mitigation. Moreover, the project used in this study used a 3-D BIM. Therefore, other projects need to be studied employing higher dimensions of BIM to reach a conclusive finding on the applicability of BIM as a risk mitigation tool.

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