

Assessment Of Construction Risk Using Mamdani Fuzzy Inference System: A Case Study Of The Construction Industry In Hyderabad City

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As per a report by the Project Management Institute in 2020, 70 percent of construction projects are prone to delays thus shedding light on the need for risk assessment in construction. In the same way that a building's footing ensures its stability, so does risk assessment guarantee safety, cost control and successful completion of any given project. The current study focused on the Internal Risk Factors in the Construction Industry Employing Mamdani Fuzzy Logic," focuses on identifying and mitigating internal risks in the construction sector of the Hyderabad region. The research is conducted in two phases: initially, the Weighted Average Index (WAI) method is employed to prioritize and identify key internal risk factors, followed by the application of the Mamdani Fuzzy Logic approach to assess the role of these factors in risk mitigation. The study frames 70 questions across seven key segments Health and Safety Risk (HSR), Quality Assurance Risk (QAR), Financial Management Risk (FMR), Technology Integration Risk (TIR), Workforce Management Risk (WMR), Procurement and Supply Chain Management (PSCM), and Health and Safety Risk (HSR) based on literature review, and collects primary data from 180 respondents using a 5-point Likert scale. The findings reveal that Health and Safety Risk (HSR) is the most significant internal risk factor, with sub-factors like HSR7 and HSR2 showing the highest weighted average scores, indicating their critical impact on construction activities. Quality Assurance Risk (QAR) and Financial Management Risk (FMR) also emerge as major concerns, underscoring the necessity of ensuring quality and robust financial management to mitigate overall risk. While Technology Integration Risk (TIR) and Workforce Management Risk (WMR) rank lower, they remain essential for effective project execution. The study highlights that even minor risk factors can escalate to severe levels, emphasizing the need for comprehensive and focused mitigation strategies. Conversely, well-managed critical risk factors can significantly reduce overall construction risk to low levels, demonstrating the importance of prioritizing high-impact areas like financial management and technology integration. The study concludes that certain risks, even when managed, can still drive overall risk to severe levels, suggesting that more intensive or specific mitigation efforts are necessary to ensure the successful completion of construction projects.

Keywords: Construction Risk Assessment, Mamdani Fuzzy Logic, Health and Safety Risk (HSR), Risk Mitigation Strategies

Introduction

The construction sector is a major factor in defining the economic and social landscape, especially within areas of quickly expanding urbanization. However, the business itself is innately risky due to the many variables that could potentially affect whether a project will succeed or fail. These risks are complex and may involve issues related to project management, availability of labour, financial stability, or integration of technologies, among others. Each of these variables leads to various challenges, which, if not properly taken care of in the case of poor quality, result in time overruns and cost overruns. Understanding these risks and finding ways to mitigate them is very important in construction projects. A fast-developing city, on the one hand, has given rise to a number of opportunities and challenges since projects will have to work in a complex environment predetermined by changes in consumer demand, law and regulation changes, and rapid technological progress. Timely, cost-effective, and quality-compliant completion of a project requires effective assessment and management of the risks involved. Major risks to the construction outcome involve poor project planning, financial mismanagement, and a lack of labour.

There are also other risks in including new technologies and their adoption and use. Thorough risk management plans by construction stakeholders that take into consideration the peculiarities of the local market must be implemented to overcome these hindrances. Through this, they can increase the rates of success of projects, encourage and motivate sustainable development, and expand the general local economy. In previous literature, several studies were carried out with the same subject matter as the current study, but some of the most prominent works are outlined in the following paragraphs.

Weems et. al., (1987) investigated the relationship between construction activities and invasive fungal infections in immunocompromised patients in a pediatric hospital case-control study. The study compared five hematologic malignancy patients who developed invasive aspergillosis (IA) or invasive zygomycosis (IZ) during hospital construction to ten autopsied patients who did not have these infections. The study looked at whether building activity was a risk factor for IA or IZ. Patients and controls were compared based on immunosuppression, granulocytopenia, and platelet transfusions. Compared to those autopsied before to construction, case-patients were more likely to have been hospitalized during construction and had a higher rate of IA or IZ. According to the study, construction activity may be an independent risk factor for invasive fungal infections in hematologic malignancies, hence hospitals should minimize exposure to construction in vulnerable populations. **Mitropoulos et. al., (2011)** developed Task Demand Assessment (TDA) to evaluate construction safety risks by analyzing operational changes that affect accident chances. The study introduced and evaluated TDA to assess "task demand" using activity characteristics rather than worker abilities. TDA was utilized to identify potential hazards and job demand components in roofing and concrete paving. TDA was demonstrated to be capable of analyzing and comparing accident potential across production scenarios, making it suitable for complex jobs. The study concluded that TDA might be used to assess and design safer building operations;

however, task demand aspects must be carefully chosen, and the technique requires more development.

NAA Karim et. al., (2012) Risk is critical to construction project success. Risk factor identification is critical for risk management. This study looked at risk indicators from the perspective of contractors, who are critical to project success. This study only includes Batu Pahat and Muar. Contractors who registered with Pusat Khidmat Kontraktor answered comprehensive surveys. The study looked at 25 common risk indicators reported in the literature, divided into five categories. Statistics were used to analyze the data. According to the findings, the top five construction project risks include material shortages, late delivery, insufficient technology, poor craftsmanship, and cash flow concerns. These significant factors stem from construction and financing. The findings of this study will assist contractors control construction dangers. **A. M. Jarkas et. al., (2015).** This research examines, ranks, and determines the allocation response patterns of Qatari general contractors' primary construction risk variables. A statistically representative sample of contractors received a standardized questionnaire with 37 risk variables. The "Relative Importance Index (RII)" was used to determine the influence ranks of the factors investigated, and the prevalent trend of contractors' attitudes toward risk allocation of each factor was quantified and expressed as a percentage based on the number of respondents who selected a specific option compared to the total number of respondents. The results show that "client" risks are the most important, followed by "consultant", "contractor", and "exogenous" hazards. The results suggest that contractors mostly choose "transfer" for "client" and "consultant" risks and "retention" for "contractor" and "exogenous" group hazards. The majority of respondents believe that clients and consultants are responsible for managing construction risks, suggesting that they are key to minimizing their negative effects. The findings imply that raising designers' knowledge of constructability's importance might significantly reduce construction hazards. Additionally, policymakers can reduce the danger of incompetent technical personnel and operatives by regulating the movement of inexperienced and unskilled construction workers into the state. Due to the knowledge gap for Qatari general contractors' major construction risk factors, this study can help clients, industry practitioners, and policy makers manage the significant risks identified, enabling them to operate cost-effectively and competitively.

Abdul El-Karim et. al., (2017) identified, researched, and evaluated the factors influencing cost and time contingency in construction projects, highlighting that cost savings and time performance are critical for all stakeholders. The study aimed to address construction project delays and cost overruns that affect the industry and the economy. The effects of owner, contractor, and environmental risk factors were investigated in sixteen Egyptian construction companies. The study employed data output charts and analytical spreadsheets to develop RIAM, a computer model for evaluating these factors. The findings revealed that building projects are complex, thus cost and scheduling must be flexible to accommodate changes without jeopardizing project objectives. The conclusion emphasized that this study's insights into risk management and planning to avoid cost and schedule overruns will assist Egypt's construction sector as developments continue. **Adeleke et. al., (2018).** proposed standards and regulations to help explain empirical research on organizational internal factors and construction risk management. The study looked at how laws and regulations influence the relationship between organizational internal features and construction risk management in

Abuja and Lagos State, Nigeria. Data from 238 employees were collected using self-administered questionnaires based on discouragement and organizational control theory. Partial least squares structural equation modeling was employed. Internal organizational factors, norms, and regulations all have a good correlation with construction risk management. Rules and regulations significantly influenced the relationship between organizational internal features and construction risk management, showing an interaction effect. These findings are significant for the Nigerian construction business since laws and regulations can enhance internal organizational risk management.

H.T. Tri et. al., (2020), focused on Construction enterprises in Vietnam, particularly SMEs, confront a difficult battle to survive and develop. This study investigates the factors influencing these enterprises' internal control systems in Ba Ria-Vung Tau Province. The COSO Framework 2013 was used to generate a variety of hypotheses utilizing quantitative and qualitative methods. More information was gathered from 304 building SME owners via surveys. The multiple regression test revealed that five factors—internal control, risk assessment, control activities, information and communication, and monitoring—all had a positive impact on systematic effectiveness, with monitoring having the greatest influence and control activities having the least. Furthermore, the legal punitive policy component had little effect on the efficacy of the internal control systems. Thus, the researchers presented several recommendations to increase awareness of internal control systems among construction SMEs' management and local government officials in Vung Tau, Vietnam. **Omer et. al., (2021)** investigated the effect of coercive pressure in mediating the link between internal organizational characteristics and risk management in construction enterprises. Recognizing the varied results of past studies, the purpose of this study was to determine if coercive coercion had a substantial impact on construction risk management. The study used partial least squares structural equation modeling to evaluate data acquired from 165 employees working in construction enterprises across the Malaysian Peninsula, drawing on discouragement, organizational control, and institutional theory. The findings showed that internal organizational elements have a considerable favorable impact on construction risk management, as does coercive pressure. Additionally, coercive pressure was discovered to modulate the link between organizational internal characteristics and risk management. The study indicated that competent leadership and a strong corporate culture, along with coercive pressure, help to reduce risk occurrences in construction operations. According to the research, construction businesses who adopt these internal elements and comply with coercive demands may produce projects on time, under budget, and with good quality, creating a benchmark for well-constructed projects. **Jeong et. al., (2021)**, sought to address the common safety issues associated with modular construction techniques, notwithstanding their inherent safety benefits over traditional onsite methods. The study looked into modular construction accident instances in the United States from 2000 to 2018, focusing on identifying safety risk variables and assessing the types and causes of these incidents. Using a causal map for analysis, the study identified the key causes and kinds of accidents in modular construction. A comparison study was also performed to distinguish between incidents in modular and conventional building scenarios. Based on the findings, the research made recommendations for reducing safety incidents and implementing effective management strategies. The study adds to the existing understanding of modular construction safety management by identifying

significant risk variables and providing insights for safety managers to improve decision-making and accident prevention tactics.

Alshihri et. al., (2022) looked at the risk variables that cause completion delays and cost overruns in Saudi Arabian government-funded building construction projects as a result of Vision 2030's increasing construction activity. A questionnaire was distributed to 200 Saudi construction project clients, designers, consultants, and contractors, who were asked about 83 risk indicators split into nine categories. To determine the most relevant risk factors, 55 valid survey responses were analyzed using the relative importance index (RII) and Risk Importance. Contractor financial concerns, progress payment delays, awarding contracts to the lowest bidder, modification requests, insufficient project planning, personnel shortages, and poor site management were identified as causes of project delays. Modification orders and low-bid contracts contributed to cost overruns as well. According to the report, Saudi Arabia's construction sector must manage customer, contractor, and labor risks in order to continue growing. **Abramov et. al., (2023)**, Construction manufacturing in Russia and Iraq confronts a number of problems. Differential features in investment and construction projects influence construction executives' decision-making, which can lead to uncertainty and major risks. The study's goal is to discover and quantify risk factors' effects on construction businesses' investment project operations. The study included hierarchical analysis, Monte Carlo simulations, and expert surveys. According to the study, utilizing such algorithms to detect and evaluate construction risk indicators can significantly improve construction businesses' project success rates. Based on the study's scientific and methodological approaches, risk factor assessment methodologies, as well as suitable compensating actions to decrease or eliminate the effect of these variables, will assist construction enterprises improve their production organization and succeed. **Nguyen Xuan Hai et. al., (2023)**, improvements in construction and facility management seek to increase efficiency, reduce costs, and safeguard the environment. This industry causes injuries, fatalities, and diseases. This study examines risk management and strategies for increasing construction productivity and safety. Methodology: This study employs statistics, qualitative analysis, synthesis, and induction. As a result, we need recommendations for risk reduction, prevention, and risk models. Originality is important, thus we must reduce such threats in order to generate safe initiatives. Finally, selecting qualified staff and developing a proper budget for each project are critical to project success. The research helps the construction industry by increasing output and efficiency via the use of immersive technologies. Project development, risk management, construction, efficiency enhancement

Ariska et. al., (2024). Construction delays are always conceivable. Recognizing dangers can help reduce delays. This research in Aceh Province looked at how risk influences construction project timelines. This study looked at 35 construction projects for 2021. A questionnaire was used to measure the impact of risk on 71 factors and 10 internal components. To measure hazard, we employed the severity index (SI). For 22 variables (31%), risk had a "Medium" effect on time. Medium risk impacts were seen in material (3 factors), equipment (5 variables), finance (5 variables), construction techniques (2 variables), labor (1 variable), contractor management (1 variable), construction safety (2 variables), contract (1 variable), and design (2 variables). Design, which changes according to site circumstances (J1), has the greatest risk impact, with a SI value of 0.606. **Tang et. al., (2024)** looked at the identification and

management of safety risk elements in subway shield construction, which is a popular technology because to its mechanization, low environmental effect, and flexibility to different levels. The study used text mining techniques to extract and show safety risk elements from risk data obtained from the "Metro Project Safety Risk Early Warning System." The technique included a literature analysis to identify gaps in safety risk management, followed by manual screening of risk reports to construct a corpus. The Jieba word separation software was used for text extraction and to create a professional thesaurus, which improved word segmentation. TF-IDF characteristics were utilized to detect high-frequency language associated with safety issues. The findings provided an initial set of risk indicators, which were tested against existing standards and norms to create a comprehensive collection. The study finished with the development of a cloud diagram for visualizing safety concerns, which would provide useful assistance for on-site safety management and knowledge reuse in future metro shield building projects.

Despite extensive research on risk management in the construction industry, there is a notable gap in the integration of advanced analytical methods, such as the Mamdani Fuzzy Logic, to specifically address internal risk factors. Previous studies have often focused on general risk management strategies or external factors, leaving a gap in understanding how internal risks such as project management, financial management, workforce management, quality assurance, technology integration, procurement, and health and safety can be effectively prioritized and mitigated. This study addresses this gap by employing a two-phase approach that first identifies key internal risk factors using the Weighted Average Index method and then evaluates the role of these factors in risk mitigation through the application of Mamdani Fuzzy Logic, providing a more nuanced understanding of internal risk management in the construction industry.

To address the issues aforementioned, the aim of the study is to assess the Internal Risk Factors in the Construction Industry Employing Mamdani Fuzzy Logic and is addressed by fulfilling the two objectives. Firstly, to identify the internal risk factors in construction activities by utilizing the Weighted Average Index method; and secondly, to examine the effectiveness of risk mitigation strategies in these activities by applying the Mamdani Fuzzy Logic approach.

Research Methodology

The present study focuses on risk mitigation in the construction sector of the Hyderabad region in Telangana state, emphasizing internal factors that contribute to risk. The study was conducted in two phases: the first phase employed the Weighted Average Index (WAI) method to prioritize and identify the top ten key internal risk factors, while the second phase applied the Mamdani Fuzzy Inference System to assess the role of these factors in reducing risk. The Methodology adopted in the current study are presented in Figure 1



Figure 1 Flowchart of the methodology adopted

The internal risk factors considered include Project Management Risk, Financial Management Risk, Workforce Management Risk, Quality Assurance Risk, Technology Integration Risk, Procurement and Supply Chain Management, and Health and Safety Risk. Data was collected from 230 stakeholders directly involved in construction activities, including site supervisors, engineers, project managers, architects, contractors, material suppliers, inspectors, and clients, across various construction segments such as residential, commercial, industrial, infrastructure, institutional, environmental, high-rise, government, and healthcare construction. Out of 230 distributed questionnaires, 180 were fully completed, making the study's sample size 180. The results highlight the critical role of the identified risk factors in mitigating risks within the construction sector.

Results and Discussion

Identification of Top Risk Factors

The table 1 represents a weighted average analysis of **Internal Risk Factors** in construction activities, focusing on seven core risk categories: Project Management Risk, Financial Management Risk, Workforce Management Risk, Quality Assurance Risk, Technology Integration Risk, Procurement and Supply Chain Management, and Health and Safety Risk. These seven categories are graphically presented in the Figure 2.



Figure 2. Segments of Internal Risk Factors

Each of the above category consists of ten sub-factors, with the table highlighting the most significant ones based on their ranking. The weighted average scores for these sub-factors range from 0.811 to 0.890, indicating varying levels of perceived risk impact within the construction sector. The study framed a total of 70 questions, with 10 questions under each of the seven segments, based on a thorough review of existing literature. Primary data was collected from respondents using a 5-point Likert scale, allowing for a detailed assessment of their perspectives on the internal risk factors in the construction industry.

Table 1 weighted average analysis of **Internal Risk Factors**

Code	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree	Total	Weighted Average	Rank
HSR7	10	35	37	60	38	180	0.890	1
HSR2	9	29	31	84	27	180	0.884	2
FMR8	8	42	41	66	23	180	0.853	4
FMR10	20	28	33	75	24	180	0.843	5
FMR7	25	24	28	70	33	180	0.839	6
QAR6	15	38	36	59	32	180	0.854	3
QAR10	25	27	35	64	29	180	0.838	7
TIR8	30	28	29	70	23	180	0.818	8

WMR 3	26	26	43	61	24	180	0.812	9
PSCM 4	12	30	38	82	18	180	0.811	10

The Table 1 examines insights into the internal risk factors affecting construction activities, organized into primary categories. The analysis uses a weighted average method to quantify the perceived importance of each sub-factor, with scores indicating how strongly each risk is felt within the industry.

Health and Safety Risk (HSR) emerges as the most significant internal risk factor, with factors HSR7 and HSR2 ranked first and second, respectively. HSR7 has the highest weighted average score of 0.890, reflecting a strong agreement among respondents about the critical nature of the risk. The high ranking of HSR2, with a weighted average of 0.884, further underscores the importance of health and safety in construction activities. **Quality Assurance Risk (QAR)** also appears prominently, with sub-factor QAR6 ranked third, having a weighted average of 0.854. This indicates that ensuring quality in construction projects is a significant concern, closely following health and safety. **Financial Management Risk (FMR)** has multiple -factors ranked in the top ten, including FMR8 (ranked 4th, 0.853), FMR10 (ranked 5th, 0.843), and FMR7 (ranked 6th, 0.839). These rankings highlight the critical role of financial management in mitigating risks within construction activities. **Technology Integration Risk (TIR)** and **Workforce Management Risk (WMR)** are also noteworthy, with TIR8 and WMR3 ranked 8th and 9th, respectively. These factors, with weighted averages of 0.818 and 0.812, point to the challenges of integrating new technologies and managing the workforce effectively. **Procurement and Supply Chain Management (PSCM)**, represented by sub-factor PSCM4, ranks 10th with a weighted average of 0.811. Although this category is lower on the list, it still represents a considerable concern, particularly in ensuring the timely and cost-effective procurement of materials and services.

Therefore, the rankings and weighted averages show that Health and Safety Risks are the biggest concerns in construction activities, followed by Quality Assurance and Financial Management Risks. The high scores across different risk categories highlight the complex challenges in construction, where ensuring safety, maintaining quality, and managing finances are crucial.

Top Risk Factor Assessment using Mamdani Fuzzy Logic.

Fuzzification is a critical step in applying Mamdani Fuzzy Logic for risk mitigation in construction activities. It involves converting crisp input variables, such as specific risk factors, into linguistic variables with fuzzy components. This process allows the model to handle imprecise or incomplete risk data effectively in decision-making. Similarly, the output control variable, which in this context refers to the level of risk mitigation, must also be converted into linguistic variables like "Low," "Medium," and "High," with associated membership functions to guide the decision-making process. The General structure of Fuzzy Expert System for Importance is as shown in the Figure 3

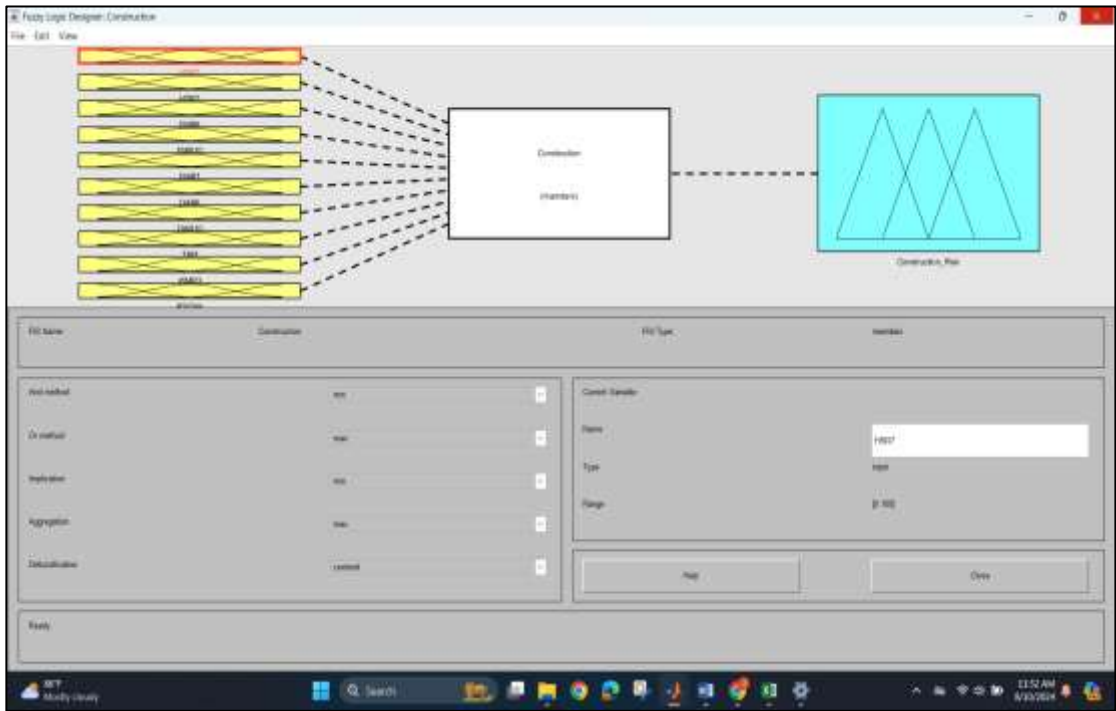


Figure 3: General structure of Fuzzy Expert System for Importance

The provided figure illustrates ten inputs variables. The middle box shows the fuzzy rules added for the fuzzy inference system, and the right-side box displays the output variable, risk mitigation

Fuzzification process Related to Importance

To implement fuzzy logic, multiple measured crisp inputs need to be mapped into fuzzy membership functions. This process is called fuzzification, and it was done in this study using triangular shapes to define the membership functions. The ranges of the input and output variables, along with their corresponding membership functions, are shown in Figure 4 to 13

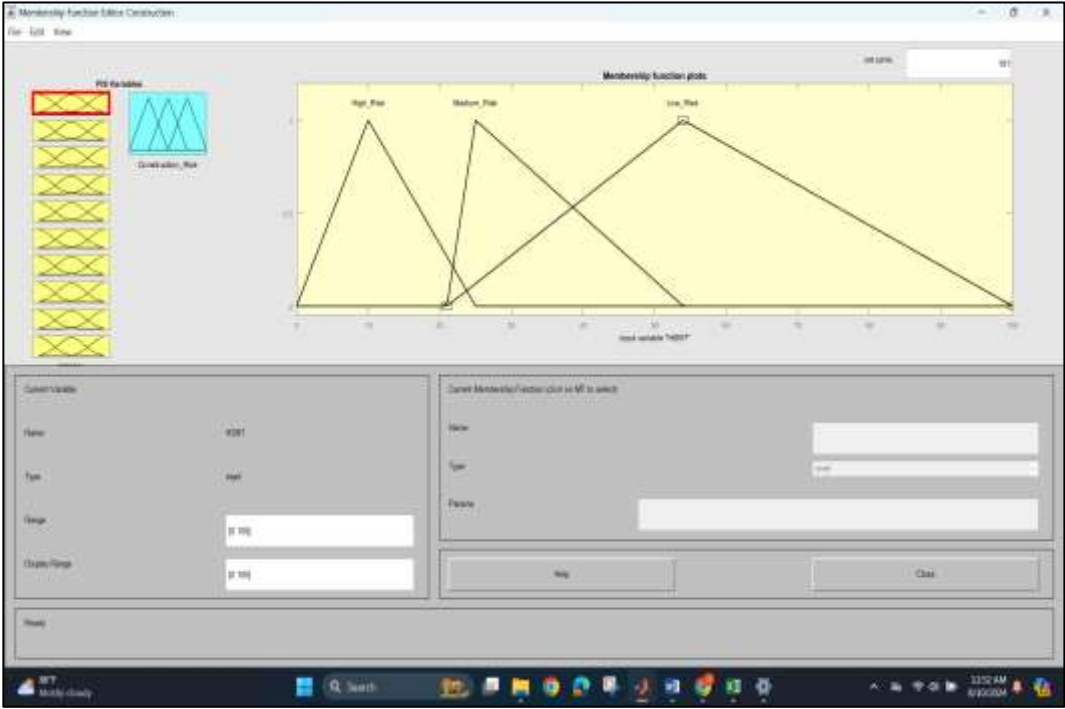


Figure 4 Membership function of Value engineering (Input function HSR7)

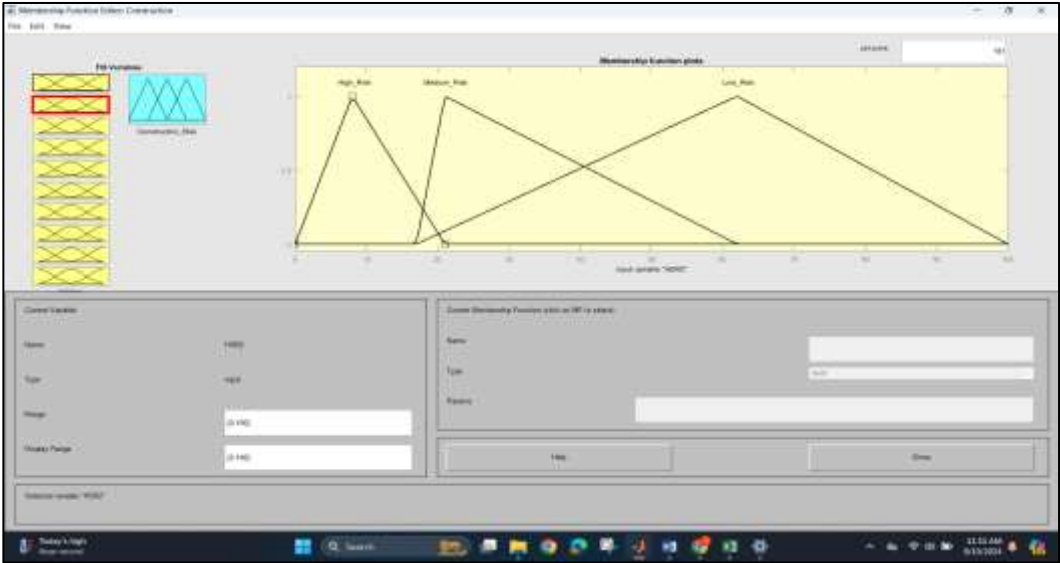


Figure 5Membership function of Health and Safety Risk (Input function HSR2)

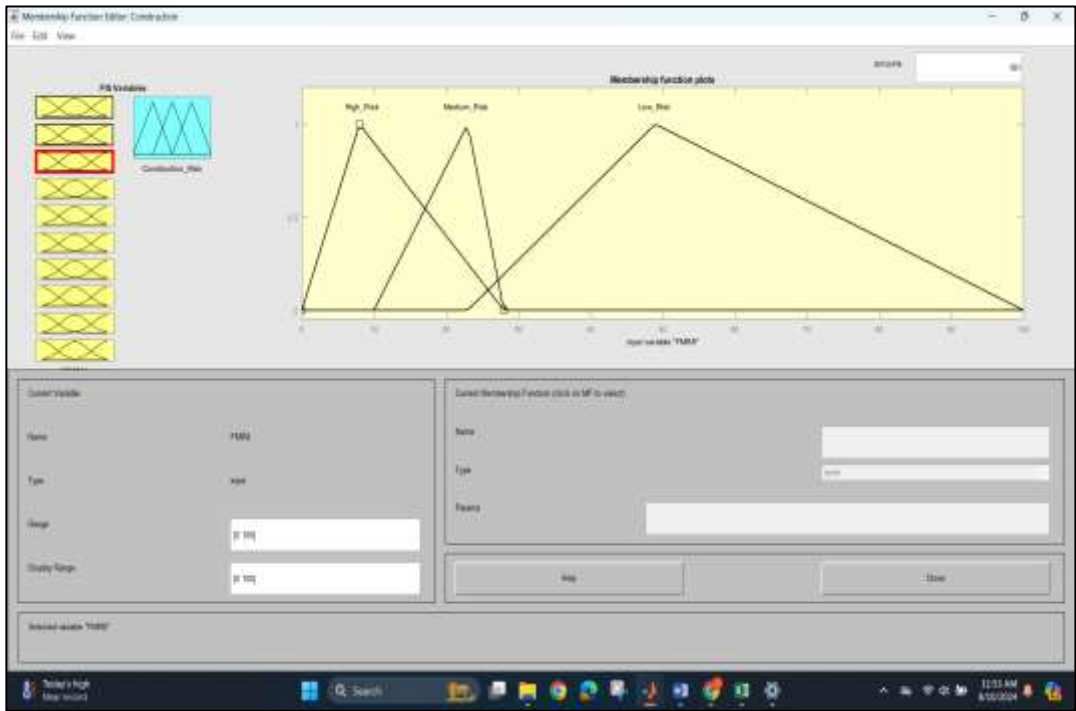


Figure 6 Membership function of Financial Management Risk (Input function FMR8)

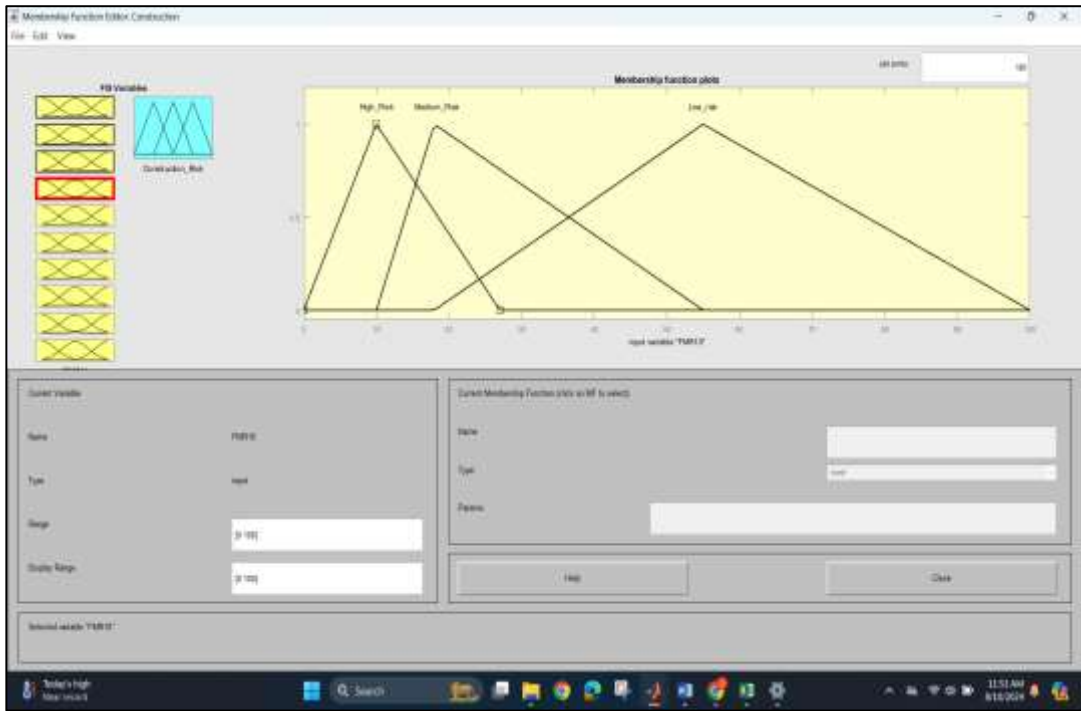


Figure 7 Membership function of Financial Management Risk (Input function FMR10)

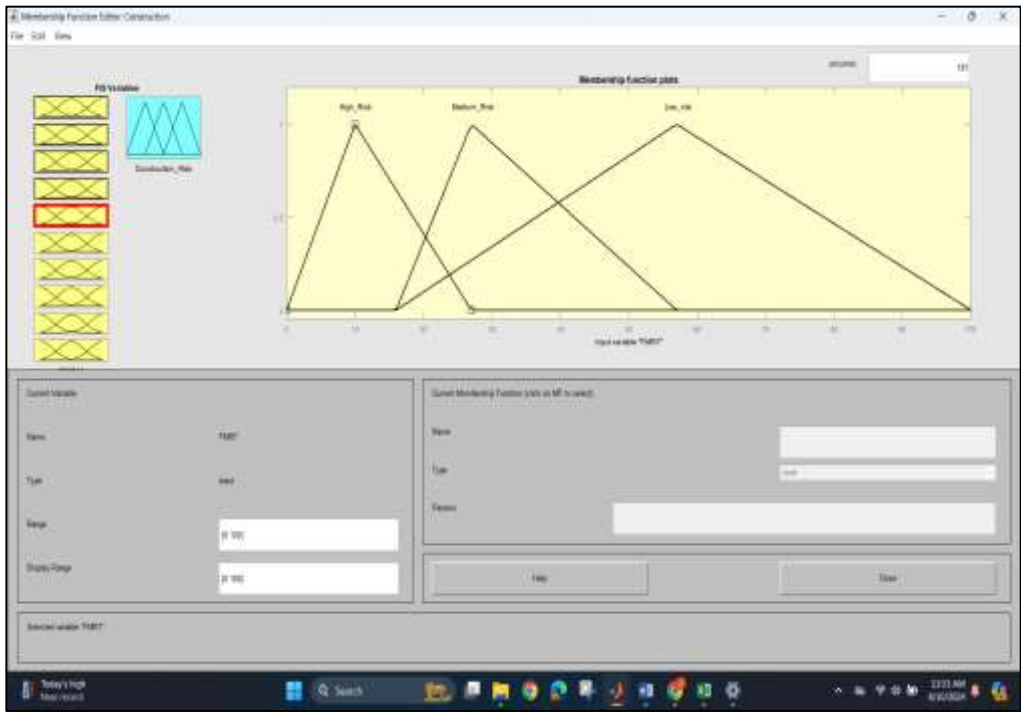


Figure 8 Membership function of Financial Management Risk (Input function FMR7)

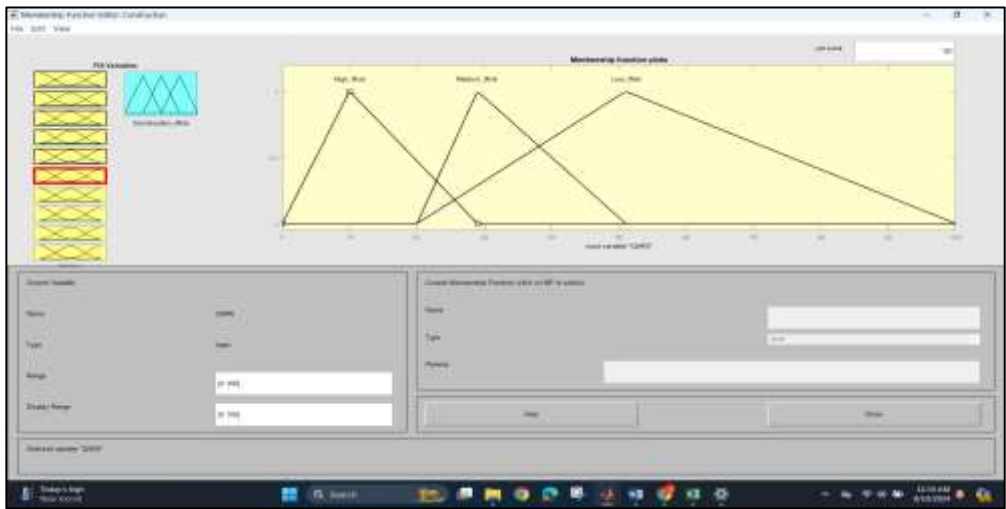


Figure 9 Membership function of Quality Assurance Risk (Input function QAR6)

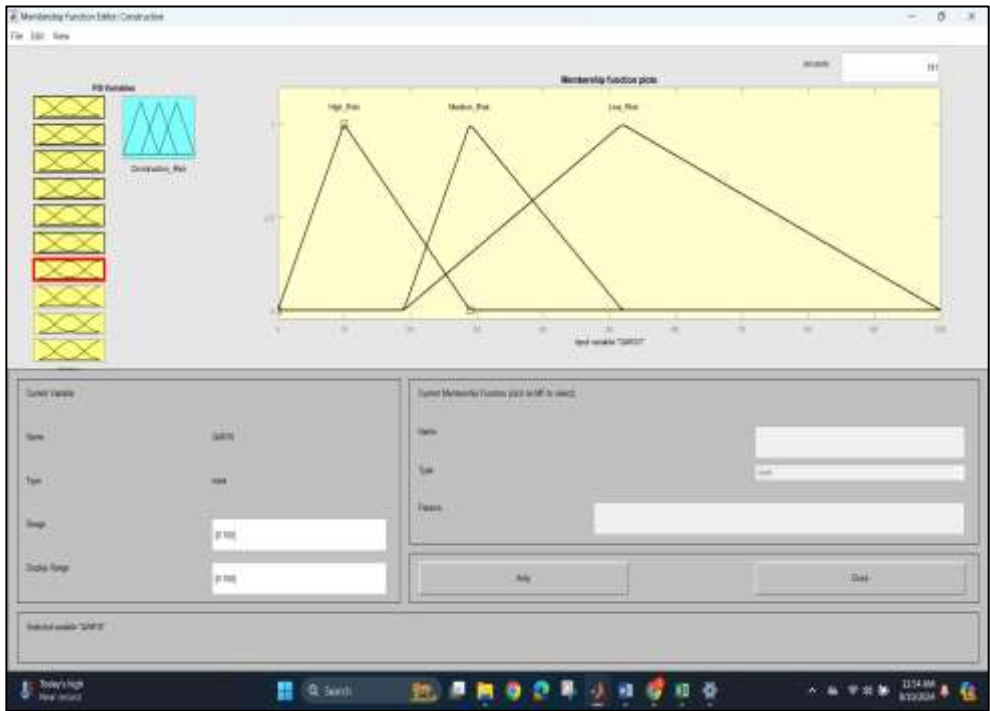


Figure 10 Membership function of Quality Assurance Risk (Input function QAR10)

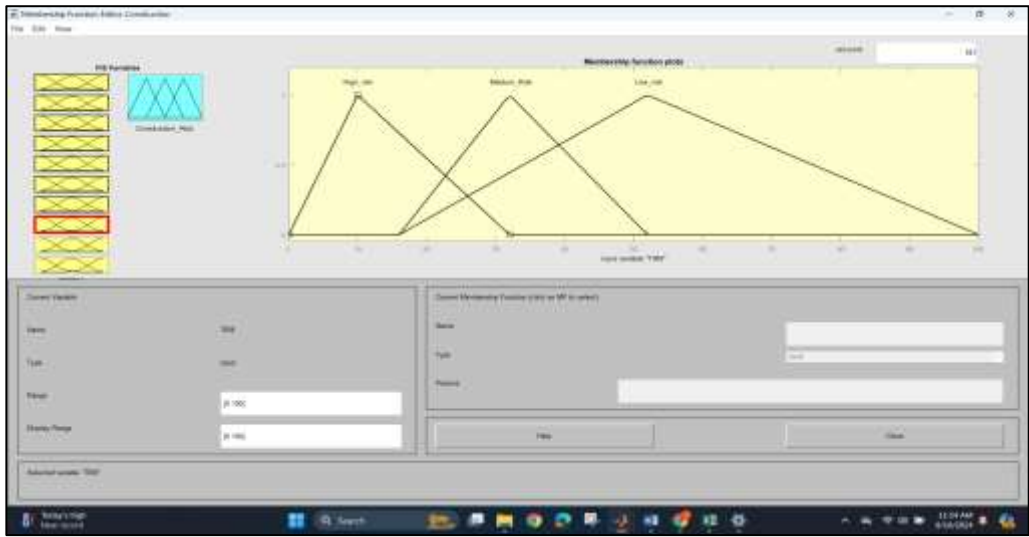


Figure 11 Membership function of Technology Integration Risk (Input function TIR8)

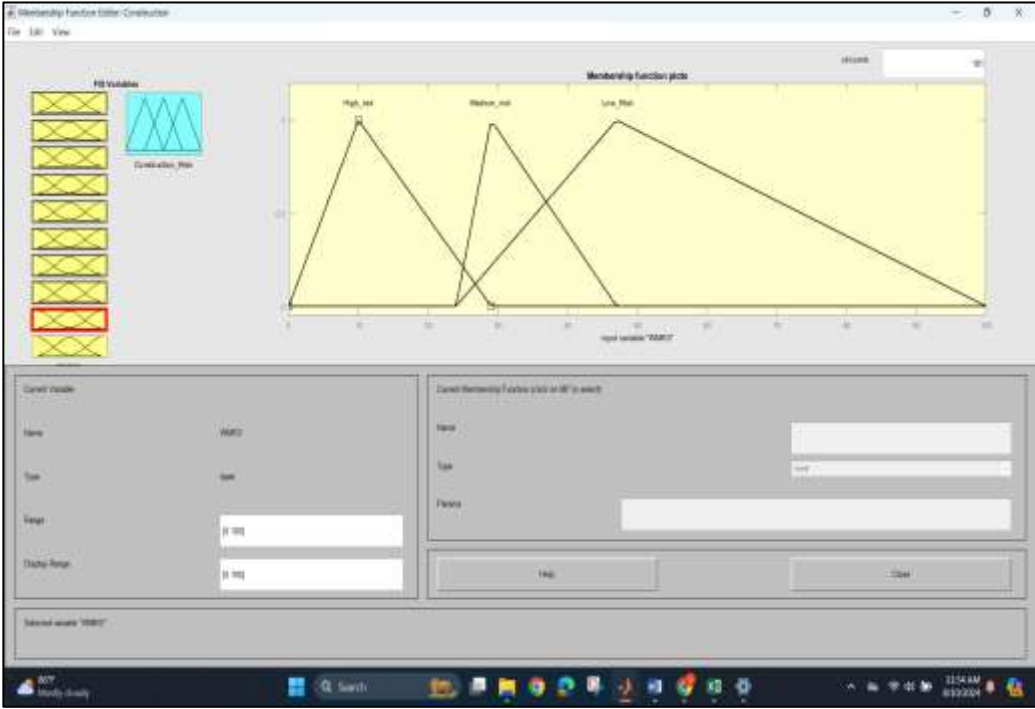


Figure 12 Membership function of Workforce Management Risk (Input function WMR3)

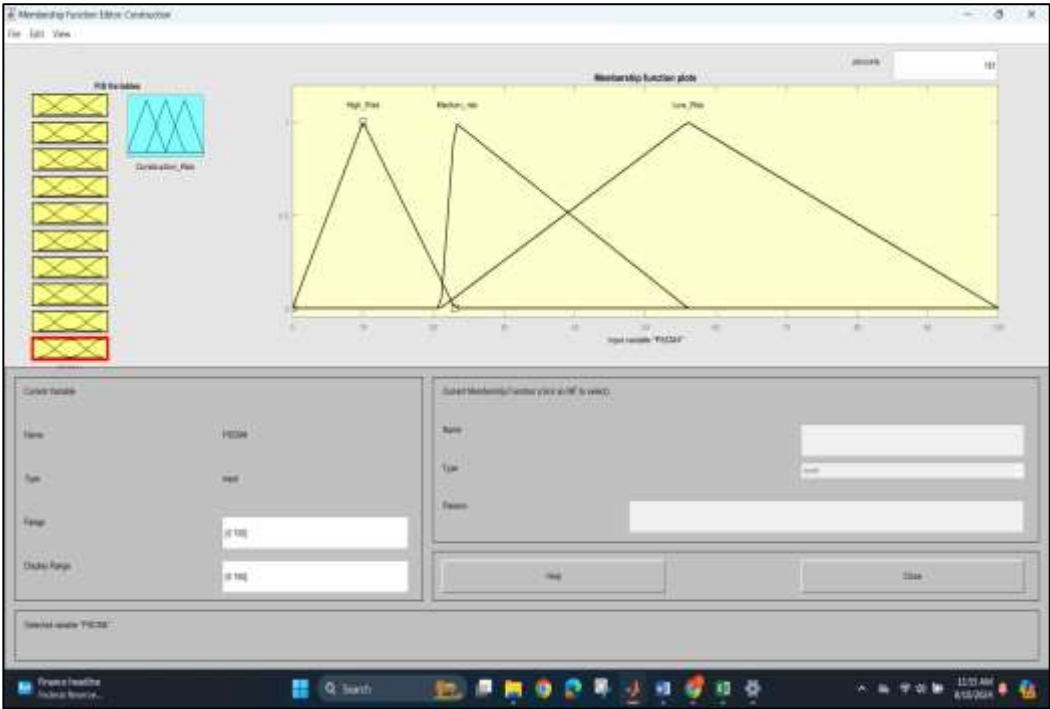


Figure 13 Membership function of Procurement and Supply Chain Management (Input function PSCM4)

In the fuzzification process, crisp numerical inputs representing various risk factors in construction projects are transformed into fuzzy sets to manage uncertainties and imprecision in the data. This transformation is achieved using triangular membership functions, which are simple yet effective in categorizing the risk levels of these factors.

Each risk factor, such as HSR7, HSR2, FMR8, and FMR10, is defined over a range of 0 to 100, with membership functions that map these values into three linguistic categories: Low Risk, Medium Risk, and High Risk. For example, a lower value of a risk factor might have a high degree of membership in the "High Risk" category, while higher values correspond to "Low Risk."

The triangular membership functions facilitate a smooth transition between these risk levels, allowing the fuzzy logic system to assess the degree of risk associated with each input accurately. This fuzzification process is crucial for the system's ability to evaluate and mitigate risks in construction projects, as it enables the integration of varying levels of risk into an overall construction risk assessment. By utilizing these fuzzy sets, the system can provide more detailed and informed decisions in managing construction risks.

Based upon the model the study has framed the following rules.,

Fuzzy rules related to Importance

1. **If** (HSR7 is High_Risk) and (HSR2 is High_Risk) and (FMR8 is Low_Risk) and (FMR10 is Medium_Risk) and (FMR7 is Low_Risk) and (QAR6 is Low_Risk) and (QAR10 is Low_Risk) and (TIR8 is Medium_Risk) and (WMR3 is Medium_Risk) and (PSCM4 is High_Risk) **then** (Internal_Construction_Risk is Severe).
2. **If** (HSR7 is Medium_Risk) and (HSR2 is High_Risk) and (FMR8 is Medium_Risk) and (FMR10 is Low_Risk) and (FMR7 is Medium_Risk) and (QAR6 is Low_Risk) and (QAR10 is Medium_Risk) and (TIR8 is Low_Risk) and (WMR3 is High_Risk) and (PSCM4 is Medium_Risk) **then** (Internal_Construction_Risk is High).
3. **If** (HSR7 is Low_Risk) and (HSR2 is Medium_Risk) and (FMR8 is High_Risk) and (FMR10 is High_Risk) and (FMR7 is Low_Risk) and (QAR6 is Medium_Risk) and (QAR10 is Low_Risk) and (TIR8 is High_Risk) and (WMR3 is Medium_Risk) and (PSCM4 is Medium_Risk) **then** (Internal_Construction_Risk is Moderate).
4. **If** (HSR7 is Low_Risk) and (HSR2 is Low_Risk) and (FMR8 is Low_Risk) and (FMR10 is Medium_Risk) and (FMR7 is High_Risk) and (QAR6 is Medium_Risk) and (QAR10 is High_Risk) and (TIR8 is Low_Risk) and (WMR3 is High_Risk) and (PSCM4 is Low_Risk) **then** (Internal_Construction_Risk is Moderate).
5. **If** (HSR7 is High_Risk) and (HSR2 is Medium_Risk) and (FMR8 is High_Risk) and (FMR10 is High_Risk) and (FMR7 is Medium_Risk) and (QAR6 is Low_Risk) and (QAR10 is Medium_Risk) and (TIR8 is High_Risk) and (WMR3 is Medium_Risk) and (PSCM4 is High_Risk) **then** (Internal_Construction_Risk is Severe).
6. **If** (HSR7 is Medium_Risk) and (HSR2 is Low_Risk) and (FMR8 is High_Risk) and (FMR10 is Low_Risk) and (FMR7 is Medium_Risk) and (QAR6 is Medium_Risk)

- and (QAR10 is Medium_Risk) and (TIR8 is High_Risk) and (WMR3 is Low_Risk) and (PSCM4 is Medium_Risk) **then** (Internal_Construction_Risk is Moderate).
7. **If** (HSR7 is Low_Risk) and (HSR2 is High_Risk) and (FMR8 is Low_Risk) and (FMR10 is High_Risk) and (FMR7 is Low_Risk) and (QAR6 is Medium_Risk) and (QAR10 is Medium_Risk) and (TIR8 is Medium_Risk) and (WMR3 is High_Risk) and (PSCM4 is Medium_Risk) **then** (Internal_Construction_Risk is High).
 8. **If** (HSR7 is High_Risk) and (HSR2 is Low_Risk) and (FMR8 is Medium_Risk) and (FMR10 is Medium_Risk) and (FMR7 is Medium_Risk) and (QAR6 is High_Risk) and (QAR10 is Low_Risk) and (TIR8 is High_Risk) and (WMR3 is Medium_Risk) and (PSCM4 is High_Risk) **then** (Internal_Construction_Risk is Severe).
 9. **If** (HSR7 is Medium_Risk) and (HSR2 is High_Risk) and (FMR8 is Medium_Risk) and (FMR10 is Low_Risk) and (FMR7 is High_Risk) and (QAR6 is Low_Risk) and (QAR10 is Medium_Risk) and (TIR8 is Medium_Risk) and (WMR3 is Medium_Risk) and (PSCM4 is High_Risk) **then** (Internal_Construction_Risk is High).
 10. **If** (HSR7 is Low_Risk) and (HSR2 is Medium_Risk) and (FMR8 is Medium_Risk) and (FMR10 is High_Risk) and (FMR7 is Low_Risk) and (QAR6 is Medium_Risk) and (QAR10 is Medium_Risk) and (TIR8 is Low_Risk) and (WMR3 is Medium_Risk) and (PSCM4 is Medium_Risk) **then** (Internal_Construction_Risk is Moderate).
 11. **If** (HSR7 is High_Risk) and (HSR2 is High_Risk) and (FMR8 is Medium_Risk) and (FMR10 is Medium_Risk) and (FMR7 is High_Risk) and (QAR6 is Low_Risk) and (QAR10 is Low_Risk) and (TIR8 is Medium_Risk) and (WMR3 is High_Risk) and (PSCM4 is Medium_Risk) **then** (Internal_Construction_Risk is Severe).
 12. **If** (HSR7 is Medium_Risk) and (HSR2 is Low_Risk) and (FMR8 is High_Risk) and (FMR10 is High_Risk) and (FMR7 is Medium_Risk) and (QAR6 is High_Risk) and (QAR10 is Medium_Risk) and (TIR8 is High_Risk) and (WMR3 is Medium_Risk) and (PSCM4 is Low_Risk) **then** (Internal_Construction_Risk is High).
 13. **If** (HSR7 is Low_Risk) and (HSR2 is High_Risk) and (FMR8 is Medium_Risk) and (FMR10 is Low_Risk) and (FMR7 is High_Risk) and (QAR6 is Medium_Risk) and (QAR10 is High_Risk) and (TIR8 is Medium_Risk) and (WMR3 is Low_Risk) and (PSCM4 is Medium_Risk) **then** (Internal_Construction_Risk is Moderate).
 14. **If** (HSR7 is High_Risk) and (HSR2 is High_Risk) and (FMR8 is High_Risk) and (FMR10 is Low_Risk) and (FMR7 is Low_Risk) and (QAR6 is Medium_Risk) and (QAR10 is Medium_Risk) and (TIR8 is Medium_Risk) and (WMR3 is High_Risk) and (PSCM4 is Medium_Risk) **then** (Internal_Construction_Risk is Severe).
 15. **If** (HSR7 is Medium_Risk) and (HSR2 is Medium_Risk) and (FMR8 is Low_Risk) and (FMR10 is High_Risk) and (FMR7 is Medium_Risk) and (QAR6 is High_Risk) and (QAR10 is Medium_Risk) and (TIR8 is Low_Risk) and (WMR3 is High_Risk) and (PSCM4 is Low_Risk) **then** (Internal_Construction_Risk is High).

Graphically the Rule 1 is as presented in the Figure 14

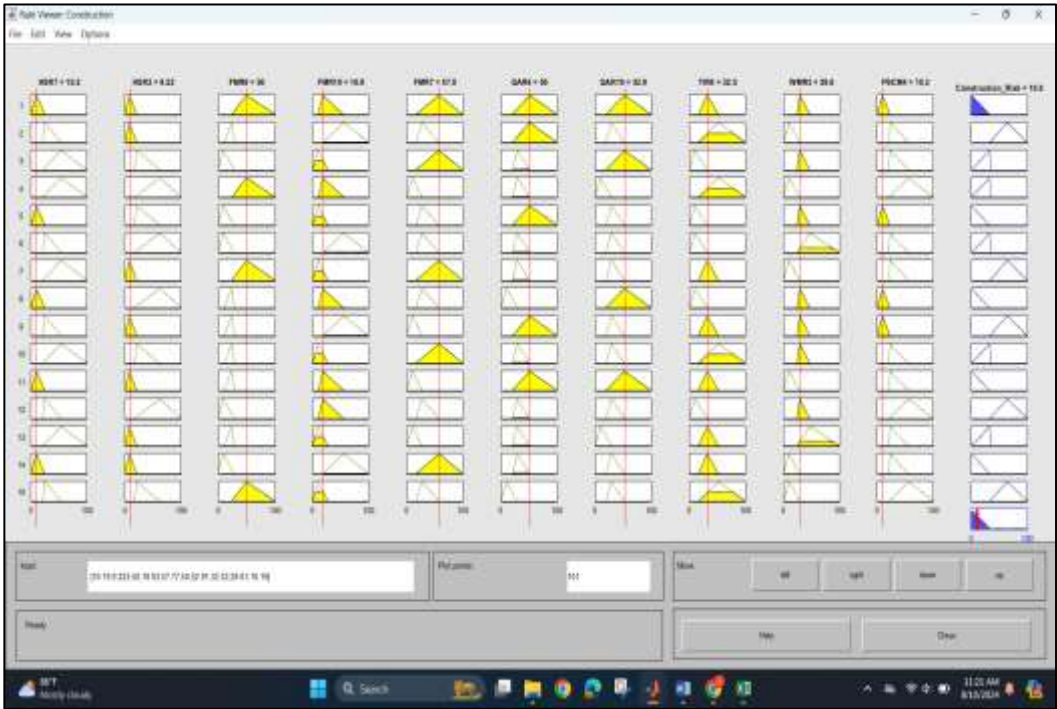


Figure 14 Fuzzy representation of Rule 1

The table 2 provided showcases the output of a Fuzzy Expert System, which is used to evaluate and ultimately mitigate risks in construction activities. The study's objective is to understand how various internal risk factors contribute to overall construction risk and to identify how these risks can be mitigated to improve safety in construction projects.

Table 2 Fuzzy Expert System Output Related to Importance

Cod e	HS R7	HS R2	FM R8	FM R10	FM R7	QA R6	QA R10	TI R8	W MR 3	PSC M4	Const- ruction Risk	Cons- t- ructi on Risk
Rul e 1	10. 20	9.2 0	9.0 0	11.3 0	7.8 0	9.0 0	9.20	12. 50	9.60	10.2 0	10.80	Seve re
Rul e 2	25. 70	9.2 2	22. 60	55.8 0	26. 70	50. 00	29.6 0	52. 90	9.22	23.8 0	65.70	Low
Rul e 3	53. 90	22. 80	8.1 7	11.2 0	57. 80	29. 60	52.9 0	11. 20	30.6 0	23.8 0	22.20	Seve re
Rul e 4	54. 90	61. 70	50. 50	18.9 0	11. 20	29. 60	11.2 0	52. 90	11.2 0	57.8 0	22.30	Seve re

Rul e 5	10.20	21.80	8.17	11.20	27.70	51.00	28.60	9.22	29.60	10.20	10.80	Severe
Rul e 6	25.70	62.60	8.17	55.80	27.70	28.60	28.60	9.22	46.10	24.80	382.20	Moderate
Rul e 7	53.90	8.25	49.50	10.20	56.80	28.60	28.60	32.50	10.20	24.80	65.70	Low
Rul e 8	10.20	62.60	22.60	19.90	27.70	10.20	52.90	10.20	30.60	10.20	10.80	Severe
Rul e 9	26.70	9.22	22.60	53.90	11.20	52.90	29.60	33.50	30.60	10.20	65.70	Low
Rul e 10	53.90	21.80	22.60	11.20	57.80	29.60	29.60	51.90	30.60	22.80	22.20	Severe
Rul e 11	10.20	8.25	22.60	20.90	9.22	51.90	52.90	32.50	10.20	22.80	10.80	Severe
Rul e 12	25.70	62.60	8.17	20.90	28.60	29.60	28.60	9.22	30.60	55.80	65.40	Low
Rul e 13	53.90	9.22	22.60	10.20	11.20	29.60	10.20	33.50	47.10	22.80	38.20	Moderate
Rul e 14	10.20	9.22	8.17	53.90	56.80	29.60	29.60	33.50	11.20	22.80	10.80	Severe
Rul e 15	24.80	22.80	48.60	11.20	27.70	10.20	29.60	52.90	11.20	56.80	65.70	Low

By examining the combinations of internal risk factors contribute to overall risk levels, the study identifies key areas where mitigation efforts should be focused to enhance safety and reduce risks. The study primarily focuses on severe risk factors, as they pose the greatest threat to the project. Moderate risk factors should also be a significant focus to prevent them from worsening. Low risk factors should be monitored and managed as part of a comprehensive strategy but with less emphasis compared to severe and moderate risks. The study effectively contributes to minimizing risks and improving safety in construction activities.

Based on the analysis, the following observations have been identified:

1. The study indicates that Health and Safety Risk (HSR) is the most significant internal risk factor in construction activities, with HSR7 and HSR2 ranked as the top two sub-factors, showing the highest weighted average scores of 0.890 and 0.884, respectively.
2. The study observes that Quality Assurance Risk (QAR) is also a major concern, with QAR6 ranked third in importance, having a weighted average score of 0.854, indicating that ensuring quality in construction projects is critical.
3. The study identified that Financial Management Risk (FMR) is crucial in mitigating construction risks, with multiple sub-factors (FMR8, FMR10, and FMR7) ranked within the top ten, with weighted averages of 0.853, 0.843, and 0.839, respectively, reflecting the significant role of financial management in reducing overall risk.

4. The study examines that Technology Integration Risk (TIR) and Workforce Management Risk (WMR) are important considerations in construction projects, with TIR8 and WMR3 ranked 8th and 9th, respectively, having weighted averages of 0.818 and 0.812, highlighting challenges related to technology integration and workforce management.
5. The study found that Procurement and Supply Chain Management (PSCM), represented by PSCM4, although ranked 10th with a weighted average of 0.811, remains a considerable concern, especially in ensuring timely and cost-effective procurement of materials and services.
6. The study indicates that even minor risk factors, as seen in Rule 1 (HSR7 at 10.20%, HSR2 at 9.20%), can combine to create significant risks, resulting in a Severe risk classification with an overall score of 10.80%, which emphasizes the need for comprehensive mitigation strategies.
7. The study observes that effective management of critical risk factors, as demonstrated in Rule 2 (FMR10 at 55.80%, TIR8 at 52.90%), can significantly reduce overall construction risk to a Low level with a score of 65.70%, underscoring the importance of focusing mitigation efforts on high-impact areas like financial management and team integration.
8. The study examines that a mix of moderate and low values in various factors, as seen in Rule 6 (HSR7 at 25.70%, HSR2 at 62.60%), results in a Moderate risk classification with an overall score of 382.20%, indicating the importance of a balanced and holistic approach to risk management to avoid the escalation of risks.
9. The study identifies that certain risk factors, despite being well-managed, may still drive the overall risk to Severe levels, as observed in Rule 14 (FMR8 at 53.90%, TIR8 at 33.50%), indicating that more intensive or specific mitigation efforts are required in these dominant areas to prevent severe risks.

CONCLUSION

The study has been emphasized on the on the Internal Risk Factors in the Construction Industry Employing Mamdani Fuzzy Logic," The study considered the Hyderabad region construction sector as the sampling area which concludes the Health and Safety Risk (HSR) is the most significant internal risk factor in construction activities, with certain sub-factors like HSR7 and HSR2 showing the highest weighted average scores, indicating their critical impact. Quality Assurance Risk (QAR) and Financial Management Risk (FMR) also emerged as major concerns, with specific sub-factors ranking prominently, highlighting the necessity of ensuring quality and robust financial management to mitigate overall risk. Additionally, the study underscores the importance of Technology Integration Risk (TIR) and Workforce Management Risk (WMR), which, while ranked lower, remain vital for effective project execution. The findings reveal that even minor risk factors can combine to escalate risks to severe levels, emphasizing the need for comprehensive and focused mitigation strategies. Conversely, well-managed critical risk factors can significantly reduce overall construction risk to low levels, illustrating the importance of prioritizing high-impact areas like financial management and technology integration. The study also identifies those certain risks, even when managed, can still drive overall risk to severe levels, suggesting that more intensive or

specific mitigation efforts are necessary to prevent severe risks, thereby ensuring the successful completion of construction projects.

Future research should also look at technologies such as AI and machine learning that can be integrated to increase risk prediction capabilities and in developing more effective mitigation strategies in all construction environments. Also the operationalization of external factors that have an effect on risks in the construction industry through an expansion of the application of Mamdani Fuzzy Logic.

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