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Construction Delay Assessment using Compound Index and Fuzzy Optimization Technique: A Case Study of Hyderabad Construction Industry

Gundurouthula Srikanth[1,*], M. Gopal Naik[1], Togiti Dhilip[1]

[1] University College of Engineering, Osmania University, Hyderabad, Telangana-07, India

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ABSTRACT

Construction projects often encounter delays that can have significant impacts on project timelines and budgets. Understanding the factors contributing to these delays is crucial for project managers to implement effective strategies for timely project completion. This study presents a comprehensive assessment of construction delays in the Hyderabad construction industry using a compound index and fuzzy optimization technique. The compound index incorporates Relative Importance Index (RII), Relative Frequency Index (RFI), Relative Severity Index (RSI), and Normal Rank to rank the factors impacting construction delays. Additionally, fuzzy logic is applied to analyze the outcomes of these factors in different scenarios. Based on the findings, the most significant factors influencing project delays are Owner/Client Related factors, Consultant related factors, and Scheduling. These factors consistently result in "No Delay" outcomes in 67% of cases, underscoring their crucial importance for minimizing project delays. Conversely, Product Related Factors and Rules and Regulations exhibit a relatively lower impact on delays, with outcomes primarily falling under "Moderate Delay" in 45% of cases. Project managers can focus on addressing these higher-impact factors to effectively manage and mitigate delays. However, it is noted that some factors, such as rules and regulations and consultant-related factors, display inconsistent outcomes across different scenarios. This variability suggests that the impact of these factors is contingent on specific circumstances or contextual factors. Hence, project managers should exercise judgment and conduct case-by-case assessments when dealing with such factors.The study emphasizes the significance of prioritizing Owner/Client Related factors, Consultant related factors, and Scheduling to minimize construction delays effectively. While Product Related Factors and Rules and Regulations should not be overlooked, they may be more manageable and subject to case-specific considerations. Adaptability and careful evaluation of contextual factors are essential for project managers in the Hyderabad construction industry to address delays and ensure successful project execution.

* *Corresponding author.*
E-mail address: srikanthcem@mail.com

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1. Introduction

Delays are a pervasive issue encountered in nearly every construction project, and their impact on project performance can be highly significant. Identifying the root causes of these delays is crucial for minimizing or avoiding their occurrence. Construction delays can be defined in various ways, as described by experts in the field. Bramble and Callahan [24] asserted that a delay refers to the period during which a specific aspect of the construction project has been extended or remains uncompleted due to anticipated circumstances. In other words, it encompasses situations where the anticipated schedule has been disrupted or prolonged. Aibinu and Jagboro [25] defined delay as a situation wherein the contractor and project owner, either individually or collaboratively, contribute to the non-completion of the project within the originally specified or agreed-upon contract period. This definition highlights the shared responsibility between the parties involved in the project and recognizes that delays can arise from either party's actions or inactions. According to Assaf and Al-Hejji [9], delay can be characterized as exceeding the completion date specified in a contract or surpassing the mutually agreed-upon delivery date for the project. This definition emphasizes the time overrun beyond the established contractual or agreed-upon timeframe.

The construction industry plays a significant role in the country's economic growth and development. However, one of the most pressing challenges faced by this industry is the occurrence of construction delays. Delays in construction projects can result in substantial financial losses, reputational damage, and overall negative impacts on project stakeholders. Therefore, there is a critical need to effectively assess and manage construction delays in order to ensure timely project completion and successful project outcomes. Assessing construction delays traditionally involves considering various factors such as project duration, schedule adherence, and completion delays. While these factors provide some insights into the delay issues, they often fail to capture the true complexity and nuances associated with construction delays. Recognizing this limitation, researchers and practitioners have emphasized the importance of adopting a multidimensional approach to delay assessment.

This research focuses on developing a comprehensive compound index for construction delay assessment in the Indian context, incorporating three key dimensions: severity, frequency, and importance. By considering these dimensions, the index aims to provide a more holistic and accurate representation of construction delays, enabling project stakeholders to better understand and address the underlying causes and impacts of delays.

The severity dimension of the compound index assesses the magnitude of the delay in terms of its impact on project timelines and critical milestones. It takes into account factors such as the duration of the delay, the extent of schedule disruption, and the financial implications for the project.

The frequency dimension evaluates the occurrence and recurrence of delays within a project or across multiple projects. By analyzing the frequency of delays, project managers can identify patterns and trends, enabling them to proactively address common causes and mitigate future delays.

The importance dimension considers the significance of the delayed activities or milestones in relation to the overall project objectives. It assesses the criticality of the delayed tasks and their impact on subsequent activities, dependencies, and overall project success. This dimension helps prioritize the management of delays based on their potential consequences.

By integrating these three dimensions into a compound index, this research aims to provide a comprehensive framework for assessing construction delays in the Indian context. The index will enable project stakeholders to systematically analyze and prioritize delays based on their severity, frequency, and importance. This, in turn, will facilitate more effective delay management strategies, resource allocation, and decision-making processes, leading to improved project performance and outcomes.

The objective of this research is to utilize a Fuzzy Inference Scheme-based Expert Systems Model to calculate the Severity Index, Frequency Index, and Importance Index for two or more types of construction delay factors. The research will involve analyzing a database consisting of 240 qualified respondents and 261 construction delay factors. By combining these individual indices, the Construction Delay Index (CDI) will be computed. The aim is to assess the effectiveness of the Fuzzy Expert System model in reducing construction delays and aiding in optimal decision making.

2. Literature Review

Kaming *et al.*, [16] conducted a comprehensive study focused on identifying the underlying factors contributing to time and cost overruns in high-rise construction projects within Indonesia. Employing a questionnaire survey of 107 projects, the researchers utilized rigorous statistical analysis to pinpoint significant factors. The results underscored that delays and cost overruns were primarily linked to inadequate planning, design alterations, and deficient site management. To mitigate these issues, the study emphasized the significance of effective planning, improved design coordination, and streamlined site management practices.

Odeh and Battaineh [20] delved into the intricacies of construction project delays, concentrating specifically on traditional contracts. Through qualitative methods including case studies and interviews, the authors examined a range of factors contributing to project delays, including suboptimal planning, communication breakdowns, and resource limitations. The research emphasized the importance of adept contract management, effective communication, and robust project planning to minimize delays and enhance project outcomes.

Al-Khalil's and Al-Ghafly [7] study focused on unraveling the causes of delays in residential construction projects within Saudi Arabia. Employing a questionnaire survey with 127 project professionals, the research identified poor site management, financing challenges, and design-related issues as the predominant causes of delays. The study highlighted the need for effective project management, improved financing mechanisms, and enhanced design coordination to mitigate delays and improve the overall performance of residential construction projects. Arditi and Pattanakitchamroon [8] aimed to uncover the factors influencing schedule delays, cost overruns, and compromised quality in public construction projects. Through a questionnaire survey of 90 public projects, the study revealed that inadequate project planning, inexperienced contractors, and design-related problems were the key culprits behind disruptions. The research called for enhanced project planning, improved contractor selection criteria, and superior design management practices to minimize disruptions and enhance project outcomes.

Assaf and Al-Hejji [9] embarked on a study investigating the sources of delays in large construction projects. Combining survey questionnaires and interviews, the authors identified design changes, subpar site management, and financial issues as the major causes of delays. The research proposed the adoption of effective project management practices, encompassing improved planning, communication, and resource allocation, to effectively tackle these delay factors and elevate project performance.

Enshassi *et al.*, [12] sought to uncover the root causes and consequences of delays within the United Arab Emirates' construction industry. By conducting a questionnaire survey involving 110 construction professionals, the study revealed that inadequate planning, poor communication, coordination challenges, and supply-related problems were the primary delay catalysts. The research accentuated the necessity for meticulous planning, refined scheduling, enhanced communication channels, and robust supply chain management to curtail delays and their adverse impacts on UAE construction projects. Le-Hoai *et al*., [17] engaged in a comparative study evaluating delays and cost overruns in large construction projects across Vietnam and other selected countries. Drawing data from diverse sources and performing rigorous statistical analysis, the authors concluded that suboptimal project planning, inadequate contract management, and insufficient project financing were central to delays and cost overruns in Vietnam. The study underscored the need for superior project planning, fortified contract management practices, and adequate financial backing to minimize delays and cost overruns.

Zou and Zhang [23] undertook research to explore the repercussions of risks on construction project timelines and costs. Employing a parametric study methodology, the authors developed a risk assessment model and conducted statistical analysis. The study examined diverse risk categories, including technical, financial, and organizational risks. The findings elucidated the significant impacts of different risk factors on project duration and costs. The research underscored the importance of proactive risk identification and management throughout the project lifecycle, recommending the integration of risk management practices into planning and decision-making processes to mitigate the adverse effects of risks.

Memon *et al*. [18] conducted an insightful research endeavor to delve into the causes of construction delays within the Malaysian construction industry. Employing a questionnaire survey among industry professionals and applying statistical techniques for data analysis, the study identified pivotal factors contributing to these delays. Key factors included inadequate site management, subpar communication, design modifications, and financial challenges. The study underscored the significance of effective project management, enhanced communication channels, and robust financial planning to effectively counteract delays in Malaysia's construction sector. Cheng *et al*., [10] embarked on an exploration of risk factors in international construction projects, focusing on their evaluation through frequency and severity measurements. Employing a quantitative research methodology involving surveys and questionnaires, the study aimed to discern critical risk factors and their repercussions on project performance. The findings illuminated significant risk elements affecting international construction projects, their varying degrees of severity and occurrence. The study emphasized the necessity of robust risk management strategies to curtail potential project delays and cost overruns.

Ibem et al., [15] dedicated their study to investigating the factors influencing contractors' cost estimating practices in Nigeria. Through a survey of contractors and subsequent statistical analysis, the research illuminated that inaccurate quantity take-offs, inadequate cost data, lack of experience, and client pressures significantly impact cost estimating practices. The study stressed the import of training initiatives, improved cost documentation, and the adoption of standardized estimating practices to enhance accuracy in cost estimation. Hussein and Tawil [14] undertook a comprehensive study aimed at identifying the roots of delays in Egyptian construction projects. Employing a combination of literature review, questionnaire surveys, and statistical analysis, the research elucidated the most pivotal contributors to project delays. Project management issues, financial constraints, and labor-related factors emerged as significant causes. The study advocated for the implementation of effective project management practices, improved financial management, and enhanced labor productivity to mitigate delays in Egypt's construction landscape.

Fang and Marle [13] endeavored to establish a benchmarking system for assessing construction project performance in China. Employing a mixed-methods approach, including literature review, expert interviews, and case studies, the study proposed a comprehensive set of performance indicators spanning time, cost, quality, safety, and environmental impact. The findings underscored the significance of benchmarking and performance measurement in evaluating project performance and uncovering avenues for enhancement. The study postulated that the benchmarking system could aid construction practitioners in monitoring and boosting project performance by comparing against industry benchmarks and best practices. Song [21] directed their attention to the cost and schedule performance of international development projects. Through the investigation of influencing factors and their interplay with project performance, the study probed into the intricate relationship between cost and schedule. By analyzing multiple case studies of international development projects, the research illuminated the multifaceted nature of project performance, influenced by variables like project size, complexity, and unforeseen events. The study spotlighted the pivotal role of effective project management strategies in ameliorating cost and schedule performance.

Wijekoon *et al*., [22] conducted a comprehensive analysis of the frequency of construction project delays utilizing diverse modeling approaches. Recognizing the presence of patterns and trends in construction delays, the authors aimed to unveil these underlying phenomena and comprehend the factors contributing to delays. This in-depth understanding is vital for enhancing project management strategies and implementing effective mitigation measures. Du *et al*., [11] introduced an extended method to assess the significance of delay factors in construction projects. Utilizing the DEMATEL method, a decision-making tool that examines interrelationships between factors, the authors aimed to systematically prioritize delay elements based on their impact. This structured approach offers insights into the cause-and-effect dynamics among these factors, aiding in the assessment of their relative importance.

Edison *et al*., [4] tackled a crucial issue by introducing a comprehensive scale designed to evaluate the intricate factors contributing to project delays. Their research identifies six overarching factors that wield significant influence over project timelines. This unveiling underscores the complexity inherent in construction project delays, furnishing a structured framework for future assessments and strategies aimed at mitigation. The study's findings hold pragmatic implications for project planning, execution, and management, particularly aiming to curtail delays and amplify efficiency in the backdrop of the Indian construction industry. In 2021, Cevikbas and Isık [6] concentrated on synthesizing existing research within the realm of delay analysis, providing a guidepost for forthcoming inquiries and industry professionals. The study discerns two primary research trajectories: the advancement of delay analysis methodologies and the proactive resolution of disputes. The research not only spotlights influential authors, sources, organizations, and countries shaping delay analysis but also offers a panoramic view of prevailing research themes, trends, and gaps. By amalgamating data, this paper supplies valuable insights into potential research avenues, uncharted territories, and evolving trends pertinent to delay analysis in the construction sector.

Garg and Saurabh [5] delved into the persistent issue of delays in the construction sector. Through their investigation, the study identifies five paramount delay factors: design alterations, delayed payments, inaccuracies in drawings, financial constraints, and suboptimal project management. On the contrary, the five least impactful factors encompass physical hindrances during construction, road closures, disruptions due to site traffic, labor disputes, and abrupt governmental regulation changes along with skilled labor availability. By delving into risk assessment and management, this study substantially contributes to refining efficiency and overall success in highway construction projects.

3. Methodology

In this research, the study delves into the proposed fuzzy model designed to estimate the relative importance of combinations of two or more construction delay factors. The development of this model involves several steps, each contributing to its effectiveness. Firstly, the study begin by identifying the delay factors based on an extensive review of past literature and interviews with field experts. This step ensures that all relevant factors are considered in the subsequent analysis. Next, the identified construction delay factors are grouped into three distinct aspects: Importance, Frequency, and Severity. This categorization allows for a comprehensive understanding of the different dimensions of delays. To gather the necessary data, we frame a questionnaire designed to capture the gradation of delay factors based on their Severity, Frequency, and Importance. This questionnaire is then used in structured interviews conducted with the participants. Using the data collected from the interviews, a Construction Delay Index (Compound Index) is developed. This index integrates the three dimensions mentioned earlier (Severity, Frequency, and Importance) to provide a comprehensive assessment of the delay factors. To compute the Output Fuzzy Sets and obtain Defuzzified values, we utilize the Fuzzy Logic Toolbox of the MATLAB Program Software. This enables the construction of a fuzzy assessment model, employing the Fuzzy Inference Scheme. Once the Fuzzy Expert System is analyzed, the goal is to identify the most crucial quantitative factors that have the potential to enhance decision-making and minimize delays in construction activities. These factors are prioritized based on their significance, aiding in making informed choices. By following this step-by-step approach, the proposed fuzzy model offers a comprehensive and systematic framework to estimate the relative importance of different combinations of construction delay factors.

The overview of the methodology adopted in the current study is shown in Figure 1.

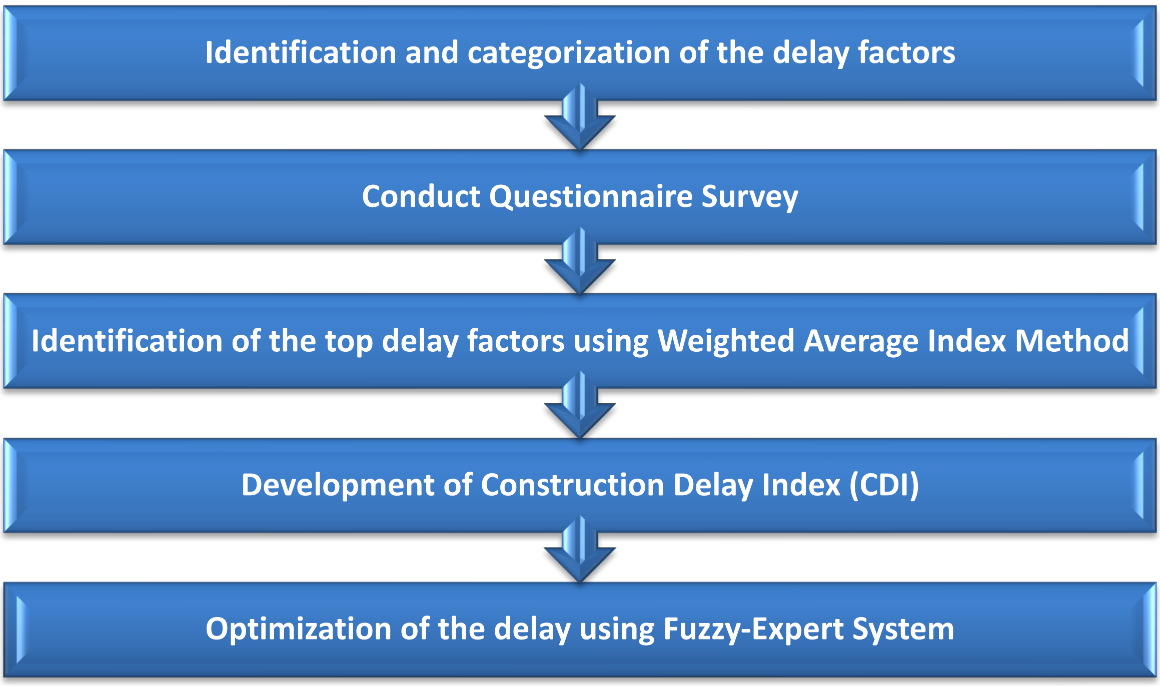

Fig. 1. Methodology adopted

Step 1: Identification and categorization of the delay factors:

To establish a rational approach and methodology for reducing construction delays, the study extensively reviewed existing practices and methodologies related to delay factors. Various journal databases, including Scopus, IEEE Xplore Digital Library, ScienceDirect, and others, were explored to collect literature on the factors causing construction project delays.

Step 2: Conduct Questionnaire Survey:

A questionnaire survey was conducted to gather insights into the practices, approaches, methodologies, and quantification aspects of framing delay factors. The survey targeted 12 distinct stakeholder groups involved in addressing delay issues. Since the data was collected from Qualified Industrial Experts, it is considered reliable and of significant importance.

Step 3: Identification of the top delay factors in all perspectives:

Based on the nature of the factors and supported by literature, all the factors were framed to obtain responses from industry experts in three dimensions: Importance, Frequency, and Severity. The study aimed to identify the top 10 factors using the Weighted Average Index method. This method assigns weights to individual data points based on their relative importance or significance, allowing for an accurate assessment of the factors' impact.

Step 4: Weighted Average Index Method:

The Weighted Average Index method is a statistical approach used to measure changes in a group of related variables over time. By assigning weights to each data point based on its relevance or importance, and then calculating the average of these weighted values, the method provides a more accurate representation of trends than a simple average. The resulting index number represents the average value of the data points, weighted according to their importance.

Muhwezi *et al.*, [19] investigated how a 5-point Likert scale, in conjunction with the Relative Importance Index Method, might be used to evaluate the causes of delays in the Hyderabad construction industry. Also in their work, on investigating the barriers in the Implementation of Sustainable Supply Chain Management in Indian Construction Industry and Sustainable Construction Supply Chain Management in India, Aditya *et al.*, [1] used the RII method. The Relative Importance index is computed as shown in equation 1.

$$RII = \frac{\sum A_i R_i}{n * R_T} = \frac{\sum W}{A \, . N} \qquad 1$$

where, A_i is the weightage on the scale, R_i is the number of responses towards the weightage A_i, R_T is the total number of responses. here, i=1 to n and n is the highest weightage on the scale.

The study utilized this method to assign weights to the delay factors and developed the Construction Delay Index (CDI) based on the three dimensions: Importance, Frequency, and Severity.

Step 5: Development of Construction Delay Index (CDI):

The Construction Delay Index is a Composite Index that combines multiple indicators or variables to measure and track the level of delay experienced in construction projects. The index considers factors such as project duration, change orders, weather conditions, labor productivity, materials availability, and regulatory compliance. Each variable is assigned a weight based on its importance, frequency, and severity, enabling a comprehensive assessment of delay factors. The CDI helps in identifying potential risks, developing mitigation strategies, and monitoring construction activities' progress, leading to improved project performance and better outcomes for all stakeholders involved.

Aditya *et al.*, [2] used a series of protocols to establish a compound index for analysing and aggregating numerous criteria that influence sustainable supplier selection in the Indian construction sector. As an industry case study, the study focuses on RMC (Ready-Mix Concrete) providers in HMA. According to the findings, this technique is a viable alternative for combining substantial quantitative and qualitative data into a coherent single metric. Steps for the development of the composite index is briefed in following part of the section.

Steps for constructing a composite index:

Constructing a composite index involves several steps outlined by Mazziotta and Pareto [26]. These steps include defining the phenomenon to be measured, selecting a group of individual indicators, normalizing the indicators to ensure comparability, and aggregating the normalized indicators using mathematical functions. The choice of indicators and aggregation methods is dependent on the specific application and requires expert knowledge. Composite indices offer the advantage of providing a unified measurement of the phenomenon, facilitating interpretation, and simplifying data analysis, enabling better tracking and comparison of performance over time.

Step 6: Optimization of the delay using Fuzzy-Expert System

Optimization of delay using a Fuzzy-Expert System involves leveraging the power of fuzzy logic and expert knowledge to make informed decisions and reduce delays in construction projects. By integrating fuzzy logic into the decision-making process, the system can handle uncertainty and imprecision inherent in construction delays, allowing for more flexible and adaptive solutions.

The Fuzzy-Expert System utilizes linguistic variables, fuzzy sets, and fuzzy rules to model and capture the expertise of domain specialists. It combines qualitative and quantitative factors to assess the severity, frequency, and importance of delay factors, providing a holistic view of the delays and their impact.

With the Fuzzy-Expert System, decision-makers can analyze different scenarios and evaluate the effectiveness of various strategies in minimizing delays. By considering the complex interactions between delay factors and their interdependencies, the system can suggest optimal courses of action, prioritize mitigation efforts, and allocate resources more efficiently.

Furthermore, the Fuzzy-Expert System can adapt and learn from real-time data and project-specific information, enhancing its decision-making capabilities over time.

4. Study Area Description

Hyderabad, the capital city of Telangana in India, is a thriving hub for construction and infrastructure development. With its rich history, vibrant culture, and rapidly growing economy, Hyderabad has witnessed a significant surge in construction activities in recent years. The construction sector in Hyderabad plays a vital role in shaping the city's skyline and contributing to its urban transformation. The city is known for its iconic landmarks, such as the Charminar and Golconda Fort, which showcase exemplary architectural marvels. Additionally, Hyderabad is home to numerous modern high-rise buildings, commercial complexes, residential townships, and infrastructure projects.

The construction industry in Hyderabad encompasses various sectors, including residential, commercial, industrial, and infrastructure development. It attracts both national and international investors, developers, and construction companies, leading to a dynamic and competitive market. The city's favorable business environment, robust infrastructure, skilled workforce, and government support have further fueled the growth of the construction sector. The construction projects in Hyderabad range from residential apartments, IT parks, shopping malls, and hospitality establishments to transportation networks, including roadways, bridges, and metro rail systems.

Moreover, the construction industry in Hyderabad has witnessed the adoption of advanced construction technologies, sustainable building practices, and innovative designs to meet the evolving demands of the city's residents and businesses. This focus on quality and innovation has positioned Hyderabad as a prominent player in the construction landscape of India. However, the rapid pace of construction in Hyderabad also brings challenges, such as managing construction delays, ensuring safety standards, and addressing environmental concerns. To overcome these challenges, the industry has been embracing technological advancements, implementing effective project management strategies, and adopting sustainable construction practices.

In Hyderabad's construction industry, there is a pressing need for a comprehensive assessment tool that accurately measures and evaluates construction delays. Existing methods often overlook the multi-dimensional aspects of delays, such as severity, frequency, and importance, creating a gap in understanding their true impact. This knowledge gap hinders effective decision-making, resource allocation, and mitigation efforts. To address this, a compound index must be developed for Hyderabad's construction delays, incorporating severity, frequency, and importance. This index will provide stakeholders with a standardized measurement that captures the intricate relationships and interdependencies among delay factors, enabling informed prioritization and efficient management of construction projects in Hyderabad

The present study focuses on assessing the delay that usually occurs during construction and classifying it into 12 different categories based on the factors causing the delay. These categories include Projects Related Factors, Rules & Regulations, Owner/Client Related Factors, Consultant Related Factors, Contractor Related Factors, Finance Related Factors, Design Related Factors, Scheduling, Labour-Related Factors, Equipment & Materials Related Factors, External & Site Related Factors, and Contract & Contractual Relational Related factors.

To assess the response towards Importance, Severity, and frequency of each factor, the study employs three metrics, namely Relative Importance Index (RII), Relative Frequency Index (RFI), and Relative Severity Index (RSI). With these three metrics, the study try to develop the Composite Index where are explain in Data analysis section. Overall, the study aims to provide valuable insights into the factors affecting project delays and their relative importance, severity, and frequency i.e., a comprehensive understanding of delay factors in all three perspectives.

5. Results and Discussion

A composite index is a statistical tool that combines multiple factors to measure the level of delay in a construction project. It can be used to identify potential risks, develop strategies to mitigate them, and monitor the progress of construction activities. Construction delays can cause significant cost overruns, schedule delays, and potential safety hazards. They occur when construction activities take longer to complete than planned or are interrupted or halted due to various reasons. Some of the most common reasons for construction delays include Inadequate planning, Unforeseen circumstances, Poor communication, Incompetent contractors. By using a composite index, civil engineers and project managers can identify potential risks early on and develop strategies to mitigate them.

5.1 Composite index of Construction Delay Factors

A Composite Index in construction can serve as a valuable tool for measuring and monitoring construction delays. It involves combining multiple variables related to project delays and assigning weights to each variable based on their importance, frequency, and severity. This index provides a comprehensive and standardized measure that allows for easier tracking and comparison of delays across different projects. By considering various factors and their relative significance, the Composite

Index enables stakeholders to assess the overall impact of delays and prioritize areas for improvement. It can assist in identifying trends, benchmarking performance, and making informed decisions to enhance project efficiency and mitigate delays in the construction industry.

After calculating the composite index, the study identified 10 factors related to construction delays, which are explained in the table below.

Table 1
Composite index with Ranking

Respondent type	Code	RII Rank	RFI Rank	RSI Rank	Norm Rank
Effective project budgeting and planning.	Project Related factor 19	11	9	5	6
Finalizing materials for the project.	Rules & Regulations 1	65	16	2	9
Obtaining necessary permissions from external authorities such as the municipality, traffic department, and environmental agencies.	Rules & Regulations 11	1	2	1	1
Resolving arbitration issues.	Rules & Regulations 13	11	7	30	10
Addressing the lack of knowledge in the approval process.	Owner/ Client Related Factor 11	2	1	60	2
Timely completion of inspection and testing by consultants.	Owner/ Client Related Factor 24	36	3	5	4
Ensuring the efficiency of the contractor.	Consultant related factor 2	22	12	8	7
Regular follow-up on site activities.	Scheduling 22	22	5	18	8
Monitoring and follow-up on payments.	Scheduling 23	11	9	3	5
Managing delays in the delivery of equipment and materials.	Scheduling 24	3	9	5	3

The table analyses the factors impacting construction delays according to their RII (Relative Importance Index) rank, RFI (Relative Frequency Index) rank, RSI (Relative Severity Index) rank, and the Normal Rank, which represents the composite index rank. Effective project budgeting and planning placed 19th in RII, 11th in RFI, and 9th in RSI, and had a Normal Rank of 6. While it may not be the most common or severe cause, it is nonetheless a substantial contributor to building delays. Finalizing materials for the project, which is related to laws and regulations, on the other hand, received a high RII value of 1, showing its relative importance. It did, however, rank lower in RFI (65) and RSI (16). Overall, it received a Normal Rank of 9, indicating that it is not the leading cause of delays. Another rule and regulation element that scored highly across all indices was obtaining relevant authorization from external authorities. With a RII score of 11, an RFI rank of 1, an RSI rank of 2, and a Normal score of 1, it implies that delays caused by obtaining approvals from external authorities are common, severe, and considerable. Resolving arbitration concerns, which is also classified as rules and regulations, received a lower RII value of 13, an RFI rank of 11, an RSI rank of 7, and a Normal value of 10. While it is not the most important or frequent cause of construction delays, it does contribute to them. Addressing the owner/client's lack of understanding in the approval process had a high RII value of 11, showing its significance. It also placed second in RFI, first in RSI, and received a Normal Rank of 2. This shows that a lack of expertise in the approval process is a major cause of delays. Another owner/client-related aspect, timely completion of inspection and testing by consultants, had a low RII rank of 24 but a higher RSI (3) and a Normal Rank of 4. Despite its low frequency, it is significant and severe in generating delays. Ensuring contractor efficiency, classed as a consultant-related criterion, rated second in RII but lower in RFI (22) and RSI (12). It received a Normal Rank of 7, indicating its significance as a factor, albeit not the most frequent or severe. A scheduling factor, regular follow-up on site activities, received a RII rating of 22, an RFI rank of 22, an RSI rank of 5, and a Normal rating of 8. While it may not be the most serious or significant cause, it does occur regularly and contributes to building delays. Monitoring and payment follow-up, another scheduling aspect, received a RII score of 23, an RFI rank of 11, an RSI rank of 9, and a Normal score of 5. It is ranked higher in importance and severity than in frequency, suggesting its impact on delays. Another scheduling element, managing delays in the delivery of equipment and materials, received a high RII rank of 24, a low RFI rank of 3, an RSI rank of 9, and a Normal Rank of 3. It is a significant contributor to delays, though not the most common or severe. The analysis of the factors that cause building delays shows that their importance, frequency, severity, and total contribution to delays in the composite index ranking vary.

5.2 Optimization of Delay Using Fuzzy Expert System

Fuzzy logic is a logical framework that builds on traditional two-value logic to allow for the use of fuzzy sets when reasoning in uncertain situations. In fuzzy sets, membership is determined by degree and there are no clear cut boundaries between the objects in the set. In 1965, Zadeh [27] made the initial suggestion for it as a way to handle ambiguous or subjective data that could not be manipulated by conventional computer logic. Numerous applications, including those for home furnishings, public transportation, and business operations, have used fuzzy logic. Incorporating fuzzy logic technology has been pioneered by Japan.

Fuzzy logic had mainly industrial uses in its early applications, but these later grew to include more beneficial uses. The comfort and effectiveness of subway rides were increased in 1987 with the opening of Sendai, Japan's first fuzzy logic-controlled subway system. Our daily lives are now impacted by the widespread use of fuzzy logic technology. In a broad sense, fuzzy logic can be seen as a tool for fuzzy control and the study of vagueness in natural language, as opposed to a narrow sense that focuses on approximate reasoning.

In fuzzy logic applications, linguistic variables are essential because they facilitate the straightforward and clear interpretation of physical variables. Decision-making is aided by fuzzy rules, which are expressed as "if-then" statements. Fuzzification, which uses linguistic variables and membership functions to represent input and output variables; fuzzy inference, which combines membership functions and fuzzy rules to produce fuzzy output; and defuzzification, which turns the linguistic variable (fuzzy output) back into a crisp or classical output, are all steps in the implementation of fuzzy logic. Soft computing techniques like fuzzy logic, which offer straightforward and acceptable solutions while tolerating imperfection and suboptimality, are used in many different fields.

5.2.1 Fuzzy Expert System Model with respect to Composite Index

The generated rules were used to determine the fuzzy output, which remained a linguistic variable classified into three levels: Low, Medium, and High. After generating the rules for the fuzzy inference system in step 2, the system was run using these rules. A total of 20 rules were framed and the results were obtained for each of them. To evaluate the accuracy of the results, they were compared with the actual outputs. This comparison allowed for an analysis of the efficacy of the Fuzzy Expert system in predicting the cause of construction delay.

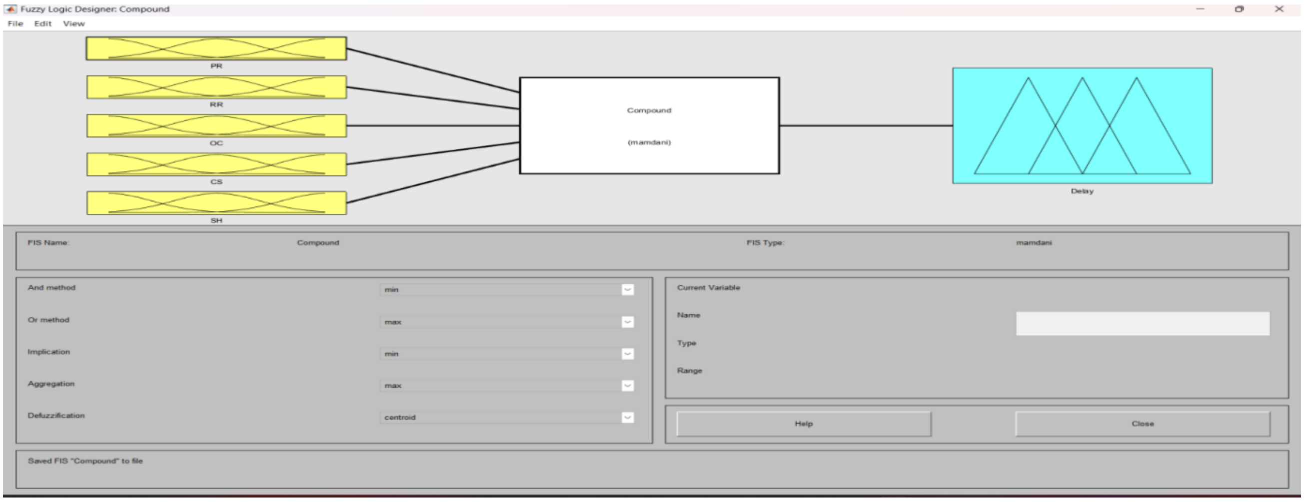

Fig. 2. General structure of Fuzzy Expert System for Composite

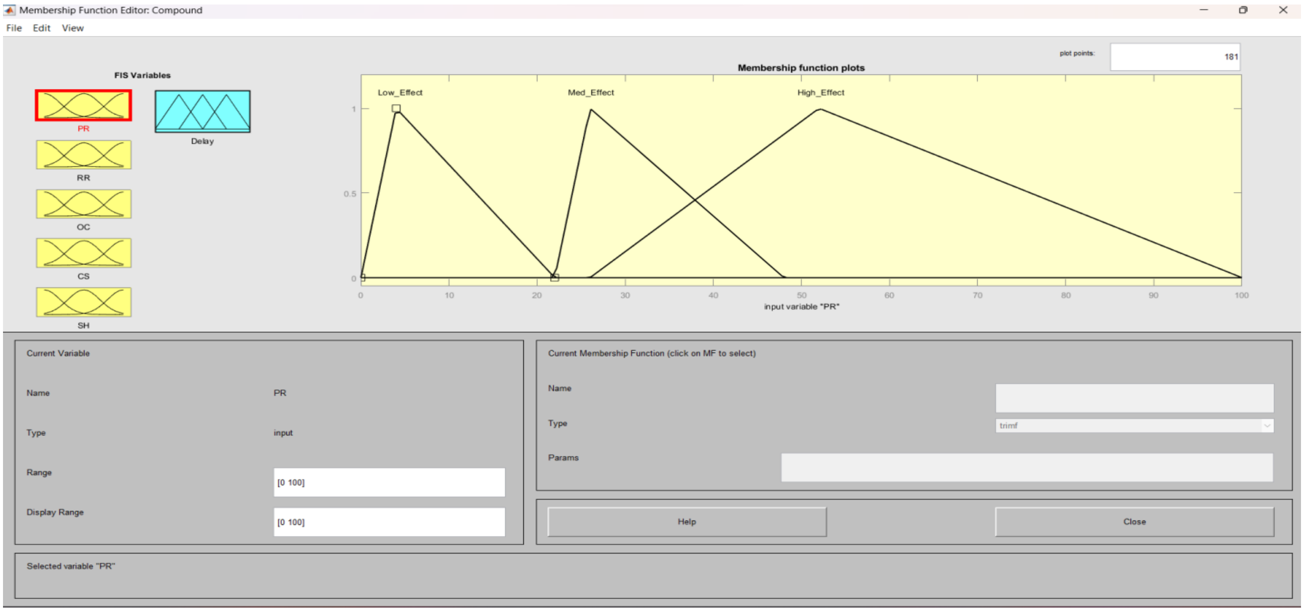

Fig. 3. Membership function of Product Related Factors (Input function PR)

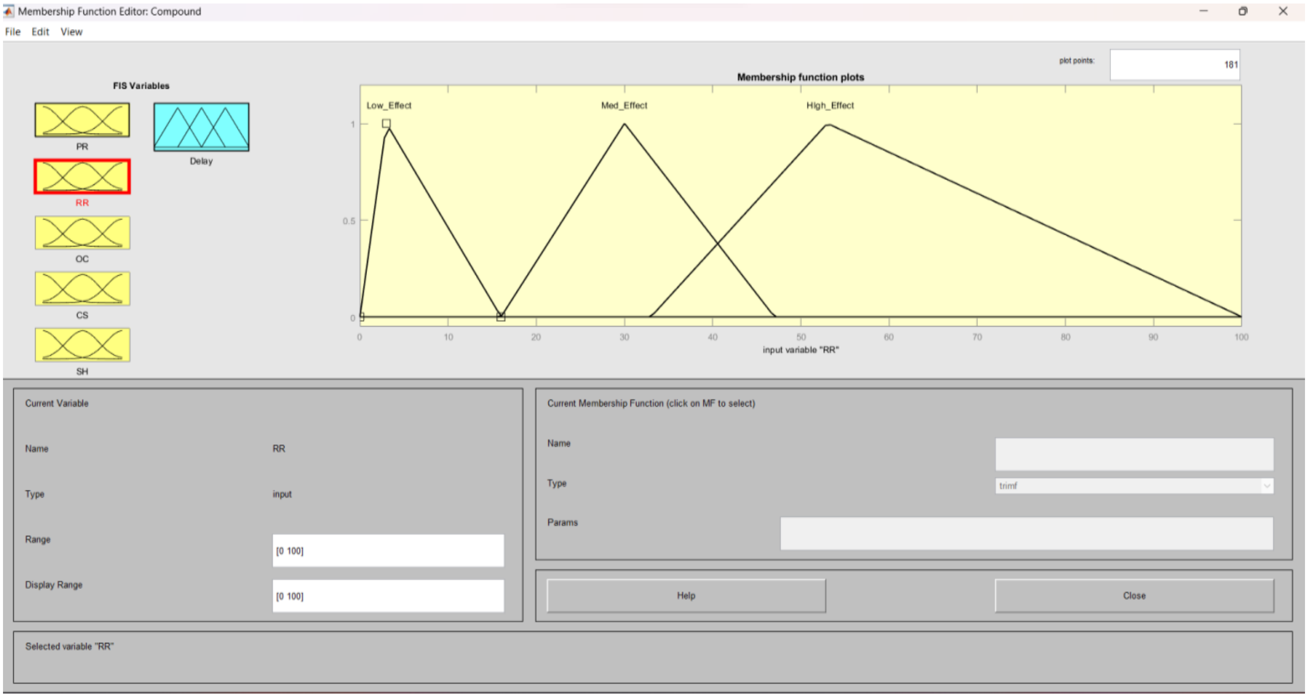

Fig. 4. Membership function of Rules and Regulations (Input function RR)

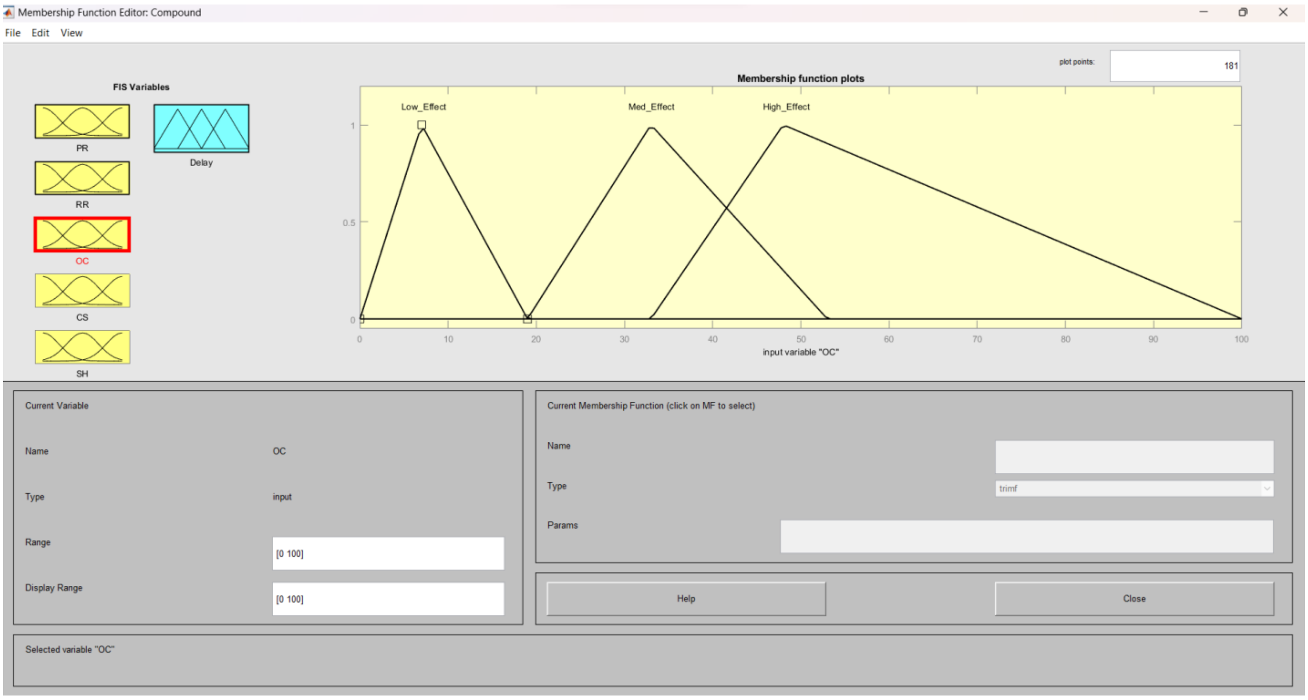

Fig. 5. Membership function of Owner/Client Related factors (Input function OC)

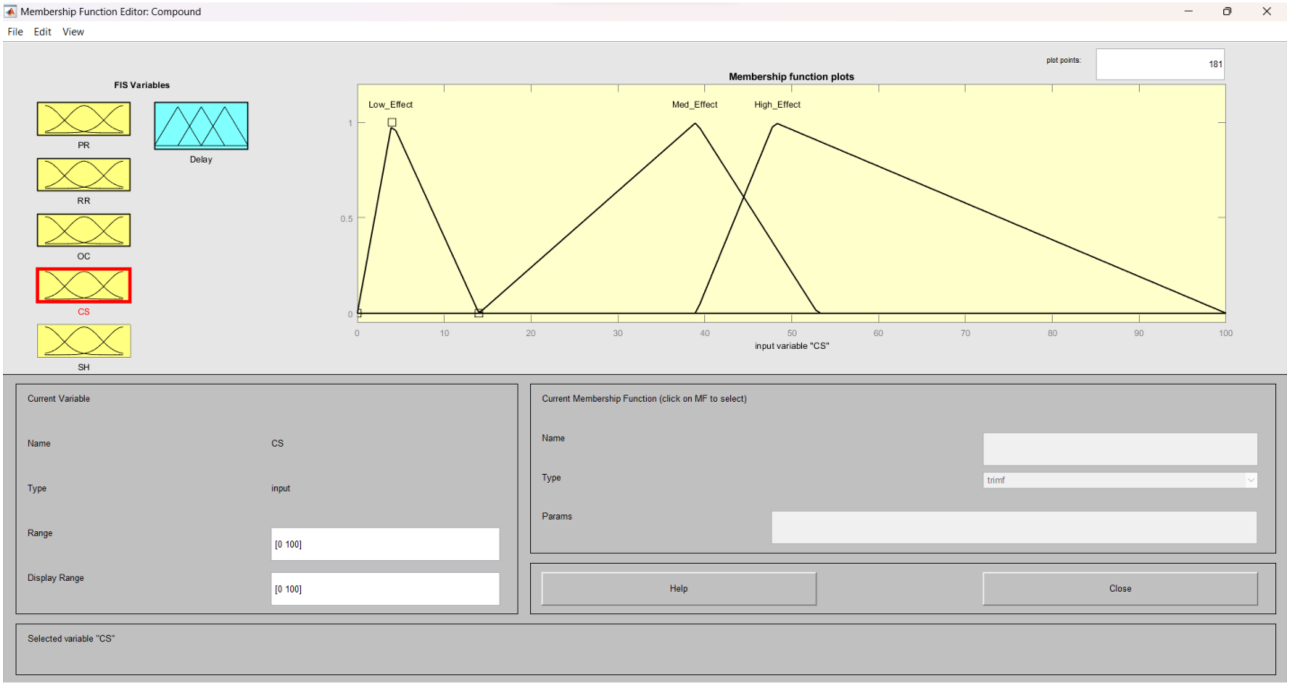

Fig. 6. Membership function of Consultant related factors (Input function CS)

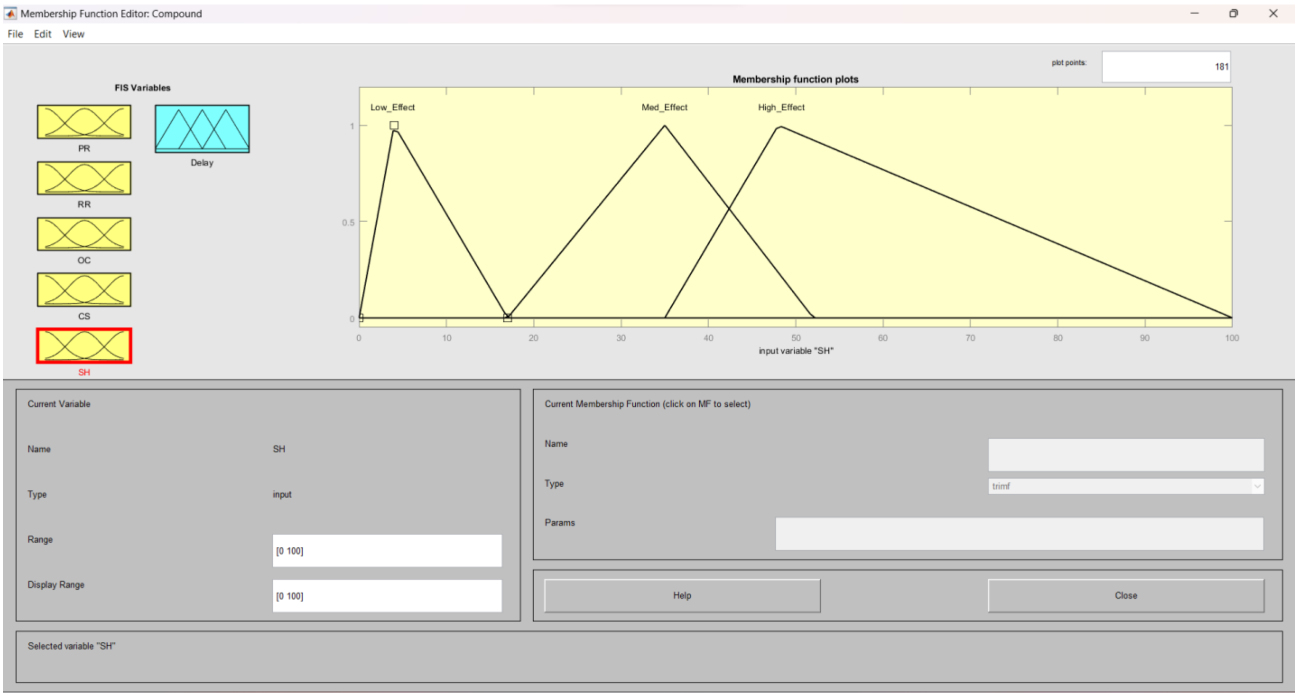

Fig. 7. Membership function of Scheduling (Input function SH)

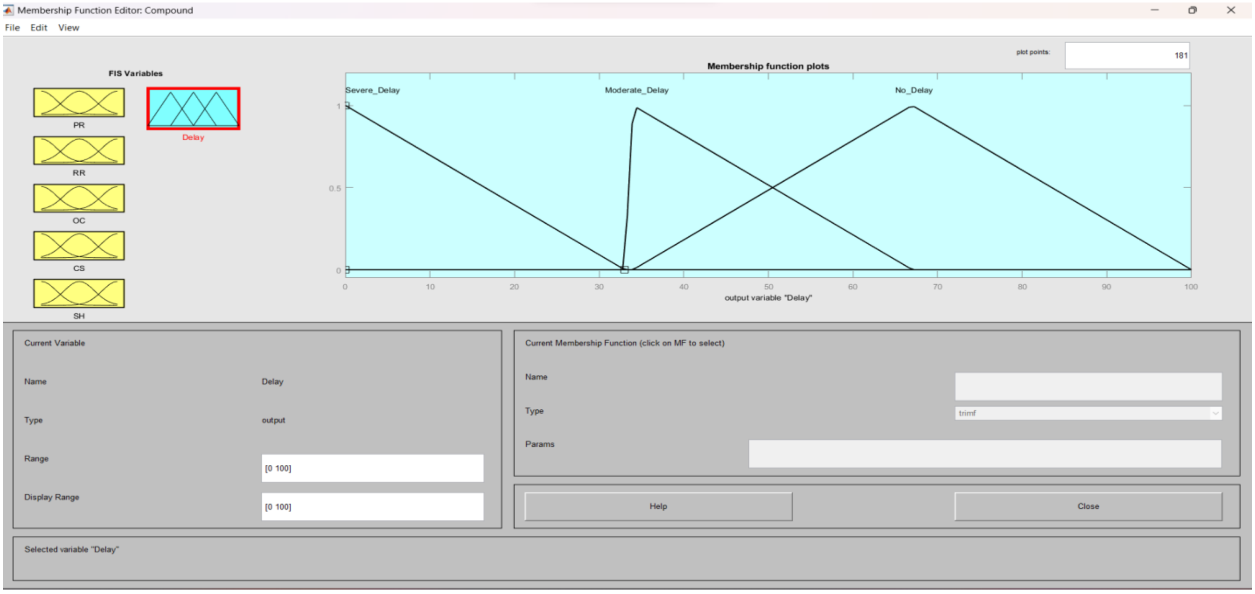

Fig. 8. Membership function of Construction Delay in the aspect of Compound (Output function)

5.3 Fuzzy rules related to Composite Index

- If (PR is Low Effectiveness) and (RR is Low Effectiveness) and (OC is Low Effectiveness) and (CS is Low Effectiveness) and (SH is Low Effectiveness) then (Delay is Severe_Delay).
- If (PR is Medium Effectiveness) and (RR is Medium Effectiveness) and (OC is Medium Effectiveness) and (CS is Medium Effectiveness) and (SH is Medium Effectiveness) then (Delay is No_Delay).
- If (PR is High Effectiveness) and (RR is High Effectiveness) and (OC is High Effectiveness) and (CS is High Effectiveness) and (SH is High Effectiveness) then (Delay is No_Delay).
- If (PR is Low Effectiveness) and (RR is Medium Effectiveness) and (OC is Medium Effectiveness) and (CS is High Effectiveness) and (SH is Low Effectiveness) then (Delay is Mild_Delay).
- If (PR is Medium Effectiveness) and (RR is Low Effectiveness) and (OC is High Effectiveness) and (CS is Medium Effectiveness) and (SH is Medium Effectiveness) then (Delay is Mild_Delay).
- If (PR is High Effectiveness) and (RR is Medium Effectiveness) and (OC is Low Effectiveness) and (CS is Medium Effectiveness) and (SH is High Effectiveness) then (Delay is Mild_Delay).
- If (PR is Low Effectiveness) and (RR is High Effectiveness) and (OC is High Effectiveness) and (CS is Low Effectiveness) and (SH is Low Effectiveness) then (Delay is Mild_Delay).
- If (PR is High Effectiveness) and (RR is Low Effectiveness) and (OC is Medium Effectiveness) and (CS is High Effectiveness) and (SH is High Effectiveness) then (Delay is Mild_delay)
- If (PR is Low Effectiveness) and (RR is High Effectiveness) and (OC is High Effectiveness) and (CS is High Effectiveness) and (SH is Low Effectiveness) then (Delay is Mild_Delay).
- If (PR is Low Effectiveness) and (RR is Low Effectiveness) and (OC is High Effectiveness) and (CS is High Effectiveness) and (SH is High Effectiveness) then (Delay is Mild_Delay).
- If (PR is High Effectiveness) and (RR is High Effectiveness) and (OC is Medium Effectiveness) and (CS is Medium Effectiveness) and (SH is Low Effectiveness) then (Delay is Mild_Delay).
- If (PR is Low Effectiveness) and (RR is Low Effectiveness) and (OC is Medium Effectiveness) and (CS is High Effectiveness) and (SH is Low Effectiveness) then (Delay is Mild_Delay).

- If (PR is Medium Effectiveness) and (RR is Medium Effectiveness) and (OC is Low Effectiveness) and (CS is High Effectiveness) and (SH is Low Effectiveness) then (Delay is Mild_Delay).
- If (PR is High Effectiveness) and (RR is High Effectiveness) and (OC is High Effectiveness) and (CS is Low Effectiveness) and (SH is Low Effectiveness) then (Delay is Mild_Delay).
- If (PR is High Effectiveness) and (RR is Medium Effectiveness) and (OC is Medium Effectiveness) and (CS is High Effectiveness) and (SH is Medium Effectiveness), then (Delay is No_Delay).
- If (PR is Medium Effectiveness) and (RR is Medium Effectiveness) and (OC is High Effectiveness) and (CS is Low Effectiveness) and (SH is Low or Medium Effectiveness), then (Delay is No_Delay).
- If (PR is High Effectiveness) and (RR is Medium Effectiveness) and (OC is Low Effectiveness) and (CS is High Effectiveness) and (SH is Low Effectiveness), then (Delay is No_Delay).
- If (PR is Low Effectiveness) and (RR is Low Effectiveness) and (OC is Low Effectiveness) and (CS is Low Effectiveness) and (SH is High Effectiveness) then (Delay is Severe_Delay).
- If (PR is Low Effectiveness) and (RR is Low Effectiveness) and (OC is Low Effectiveness) and (CS is High Effectiveness) and (SH is Low Effectiveness) then (Delay is Severe_Delay).
- If (PR is Low Effectiveness) and (RR is Low Effectiveness) and (OC is High Effectiveness) and (CS is Low Effectiveness) and (SH is Low Effectiveness) then (Delay is Severe_Delay).

5.3.1 Defuzzification Related to Composite Index

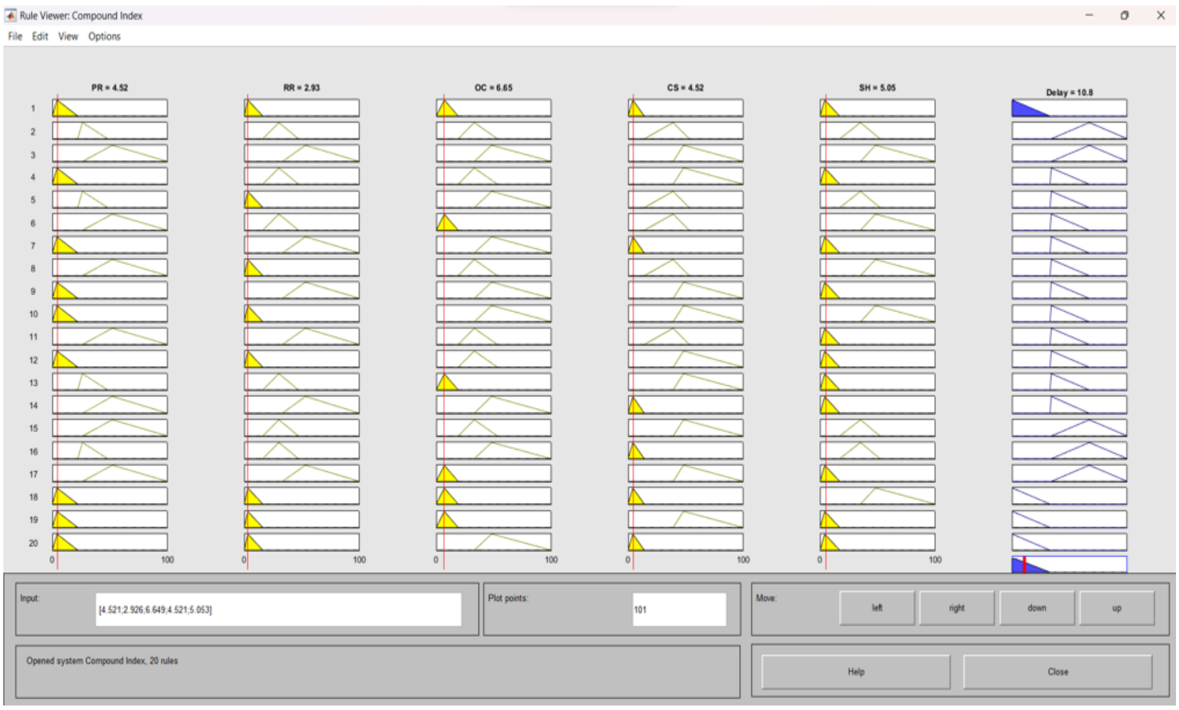

Fig. 9. Fuzzy Ruler related to Importance and rest of Composite Index fuzzy ruler

Table 2
Fuzzy Expert System output Related to Composite Index

S.no	Product Related Factors	Rules and Regulations	Owner/Client Related factors	Consultant related factors	Scheduling	Delay	Output
1	5%	3%	7%	5%	5%	11%	Severe Delay
2	26%	29%	34%	39%	35%	67%	No Delay
3	51%	52%	50%	49%	48%	67%	No Delay
4	4%	31%	33%	49%	5%	45%	Moderate Delay
5	27%	3%	48%	40%	35%	45%	Moderate Delay
6	53%	31%	7%	40%	49%	45%	Moderate Delay
7	5%	52%	49%	5%	4%	45%	Moderate Delay
8	52%	4%	33%	39%	49%	45%	Moderate Delay
9	5%	54%	48%	49%	4%	45%	Moderate Delay
10	5%	3%	48%	49%	48%	45%	Moderate Delay
11	52%	52%	33%	39%	4%	45%	Moderate Delay
12	4%	4%	33%	48%	4%	45%	Moderate Delay
13	27%	30%	8%	48%	4%	45%	Moderate Delay
14	51%	54%	49%	5%	4%	45%	Moderate Delay
15	51%	30%	32%	48%	35%	67%	No Delay
16	26%	30%	49%	5%	35%	67%	No Delay
17	52%	54%	7%	47%	4%	67%	No Delay
18	6%	5%	7%	4%	50%	11%	Severe Delay
19	6%	5%	7%	48%	6%	11%	Severe Delay
20	6%	5%	49%	4%	6%	11%	Severe Delay

Source: Primary Data

The factors that have the most significant influence on project delays are the Owner/Client Related factors, Consultant related factors, and Scheduling. These factors consistently result in No Delay outcomes i.e., 67%, indicating their crucial importance for project managers aiming to minimize delays. Conversely, Product Related Factors and Rules and Regulations show a relatively lower impact on project delays, with outcomes primarily falling under Moderate Delay i.e., 45 %. While still significant, these factors may be more manageable and easier to mitigate compared to the higher-impact factors. It is observed that some factors, such as rules and regulations and consultant-related factors, exhibit inconsistent outcomes across different scenarios. For instance, rule and regulation-related factors can lead to severe delay i.e., 11 % in certain cases while causing no delay in others. This signifies that the impact of these factors is heavily dependent on specific circumstances or contextual factors. Project managers should exercise judgment and conduct case-by-case assessments when dealing with such factors. It reveals that, project managers should prioritize addressing Owner/Client Related factors, Consultant related factors, and Scheduling to minimize delays effectively. While Product Related Factors and Rules and Regulations should not be disregarded, they may be more manageable and subject to case-specific considerations. Adaptability and careful evaluation of contextual factors are essential for effectively managing project delays.

6. Conclusion

Construction delays refer to the unanticipated prolongation of the construction process beyond the originally planned schedule, resulting in project completion delays and potential financial implications. The study focus on factors impacting construction delays reveals a varied landscape of causes, with different factors showing varying degrees of importance, frequency, severity, and overall contribution to delays. However, based on the fuzzy logic study, certain categories consistently emerge as having a significant influence on project delays: Owner/Client Related factors, Consultant related factors, and Scheduling. Owner/Client Related factors, such as the client's lack of understanding in the approval process, consistently rank first in importance and severity across multiple indices. This indicates that addressing owner/client-related issues is crucial for minimizing delays. Project managers should focus on improving communication, providing guidance, and ensuring that clients have a clear understanding of the approval process. Consultant related factors, including the efficiency of contractors and the timely completion of inspection and testing, also hold substantial importance. While these factors may not be the most frequent or severe, they consistently contribute to delays. Project managers should emphasize effective coordination and communication with consultants to ensure smooth project progress. Scheduling factors, such as regular follow-up on site activities and managing delays in equipment and material delivery, show consistent frequency in causing delays. While they may not always be the most severe, their regular occurrence highlights the need for vigilant monitoring and proactive management. Project managers should prioritize effective scheduling, follow-up, and contingency planning to mitigate delays. On the other hand, Product Related Factors and Rules and Regulations are identified as having a relatively lower impact on project delays. While they should not be disregarded, their outcomes primarily fall under the categories of Moderate Delay or Severe Delay. This indicates that they may be more manageable and subject to case-specific considerations. Project managers should exercise judgment, adaptability, and careful evaluation of contextual factors when dealing with these factors.

It concluded that to minimize delays project manager or stake holders should prioritize addressing Owner/Client Related factors, Consultant related factors, and Scheduling. These factors consistently demonstrate significant influence and contribute to No Delay outcomes. While Product Related Factors and Rules and Regulations are still significant, they may be more manageable and easier to mitigate compared to the higher-impact factors. Therefore, project managers should exercise adaptability, evaluate contextual factors, and conduct case-by-case assessments to effectively manage project delays.

Further scope for study in construction delays could involve exploring specific strategies and best practices for addressing Owner/Client Related factors, Consultant related factors, and Scheduling to minimize delays. Additionally, analyzing case studies and real-life scenarios to understand the contextual factors that influence the impact of Product Related Factors and Rules and Regulations on delays would provide valuable insights for project managers. Furthermore, investigating the role of advanced technologies and innovative approaches in mitigating construction delays could be a fruitful area of research.

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