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An Analysis of Success in Supply Chain Management for Construction Projects: Fuzzy Inference System Application

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ABSTRACT

This paper presents a framework for assessing the practicality of supply chain management (SCM) in residential construction projects in Shiraz, Iran, through an examination of critical success factors. These factors are categorized into soft factors and hard factors. Soft factors include cultural elements (organizational culture, communication and trust, and participation and teamwork) and managerial elements (leadership support and commitment, customer orientation, and human resources management). Hard factors comprise purchase and quality management, information technology, and risk management. Fuzzy logic offers a rational approach for categorizing and assessing the critical success factors. Through fuzzy inference systems, the adaptability and speed of soft computation are amplified, offering a sophisticated means to handle imprecise data. The research Findings suggest that the effectiveness of SCM is primarily determined by hard factors, particularly risk management. The study ranks constituent elements of both soft and hard factors, providing valuable insights for construction project managers in Shiraz, Iran, emphasizing investment in IT, quality purchase management, and risk management.

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1. Introduction

Construction is a significant economic driver in many developing countries, serving as the second-largest employer of both skilled and unskilled labor [1]. Because of its prominence, its efficiencies and successes are critical to a large portion of the population.

Roughly 30-35% of employment is directly or indirectly affiliated with the construction sector in these countries [2], implying that even minor advances in the field can have a significant impact on the lives of many people. Supply chain management (SCM), moreover, is a relatively new focus in the construction industry. Researchers have worked hard to expand its use in the industry, improve efficiency and project outcomes [3]. Given SCM's extensive influence on organizational processes ranging from production to customer service delivery, this endeavor is critical. However, the competitive dynamics between companies have extended beyond the performance of individual firms to the efficiency and effectiveness of their respective supply chains. As a result, SCM has become an essential strategy for gaining a competitive advantage [4]. This is also seen in the construction industry, where a multifaceted network of activities adds to both economic value and customer satisfaction. These responsibilities include everything from design and contract management to material procurement, production, and facility management [5]. Traditional construction processes have been complicated, resulting in low profitability. Long command chains, complicated relationships, and unequal risk allocation among industry stakeholders can all stifle innovation [6]. SCM provides a way to navigate these complexities by understanding the processes that are critical to customer profitability. The industry demanded a structure that fosters relationships while also remaining flexible in the business environment [7]. Many stakeholders see the value of implementing SCM principles, particularly in sectors such as residential construction where projects may be sporadic [8]. Nonetheless, the impact of supply chain principles has spread beyond the construction industry, with applications in industries such as manufacturing. With large investments being directed toward construction projects, research into integrating supply chains in this domain has accelerated. Several key factors have been identified that can significantly improve the success of SCM-enabled construction projects.

Despite these insights, the utilization of supply chain management benefits in residential construction projects in developing countries has made insufficient progress. The purpose of this research, therefore, is to identify and prioritize the critical elements for successful SCM in construction projects, with a focus on case studies from the developing world. The study includes a novel approach to calculating the success rate of these factors for each project, providing additional precision and insight into the potential of SCM in construction. This study, as a result, serves as not only a valuable resource for the used case belonging, but it is also useful for those looking to optimize residential construction projects.

2. Literature review

During the 1980s, organizations focused on systems such as on-time production, Total Quality Management (TQM), and others to achieve long-term competitive advantages. These advantages, however, proved to be less long-lasting because they were susceptible to imitation

by competitors. Efforts to optimize organizational processes in isolation, without taking into account external stakeholders such as suppliers and customers, appeared to be futile. Instead, organizations that worked together to achieve common goals performed better [9]. The supply chain received extensive coverage in various newspapers and magazines in 1990, becoming a popular topic among many professors and pioneers. A supply chain, in general, includes a variety of activities such as procurement, inventory management, sourcing and purchasing, production planning, inter-organizational relationships, and performance measurement [10]. The complexity of the business world, economic developments, intense competition, new technologies, and rapidly changing customer needs have compelled modern organizations to capitalize on quick information flow, group decision-making, improved coordination with business partners, and comprehensive strategies. These developments culminated in the supply chain, which primarily aims to maximize value [11]. Various people have proposed various definitions for the supply chain, one of which describes it as a circular network of related and interdependent organizations that work together to control, manage, and improve the flow of materials and information from suppliers to end users [12].

The supply chain is a critical business process that includes the procurement of raw materials and parts, product manufacturing and assembly, warehousing, registration, and tracking of distribution orders across multiple channels, culminating in the final delivery to the customer. Suppliers, vendors, manufacturers, and retailers are all part of this vast network, which is linked by information and financial transportation infrastructure [13]. Furthermore, the supply chain includes a collection of organizations and individuals who are either directly or indirectly involved in creating value for the customer [14].

Previously, the supply chain network was divided into distinct sections, each of which operated independently and pursued separate goals, sometimes at odds with one another. As a result, a mechanism to integrate these goals and functions became necessary. Organizations can achieve such integration through supply chain management [15]. In other words, changes in today's business environments caused by shifts in customer needs create uncertainty in decision parameters, necessitating supply chain flexibility to address these uncertainties. The supply chain is made up of various components and parts [16]. Its primary goal is to meet the needs of customers while also profiting the chain. As a result, the goal of supply chain management is to effectively meet customer demand by delivering the desired product at the lowest possible cost and in the shortest possible timeframe. Having a strategy map to integrate and coordinate all chain components and align improvements toward the ultimate goal becomes a critical and effective step in accomplishing this. To optimize internal processes, each member of the chain must collaborate with others. Successful supply chain implementation necessitates rapid and continuous market response, organizational dynamism, attention to organizational growth and flexibility, and meeting customer expectations [17–19].

According to these definitions, supply chain management aims to reduce total production costs by optimizing product flow within manufacturing processes and improving information flow among business partners. Furthermore, it seeks to reduce inventory costs through effective production and demand coordination. Finally, its goal is to improve customer satisfaction by

providing quick services, streamlining ordering processes, and encouraging greater flexibility in collaboration with distributors [20]. Supply chain management has emerged as a critical production theory in the context of twenty-first-century organizational improvement. Its significance lies in promoting supplier and customer cohesion and integration, thereby increasing the accountability and flexibility of production organizations [21]. Following in the footsteps of the retail and manufacturing industries, the construction industry has embraced SCM to improve efficiency and competitiveness. The construction industry provides employment opportunities for people from all walks of life. Minor changes in environmental conditions and construction practices can have a significant impact on society, particularly on low-wage workers. A construction project typically involves multiple stakeholders, including a client, contractor, consultant, and subcontractors [22].

The client initiates a construction project, which includes ideation, financial arrangements, and supply chain integration. A consultant can help by providing feasibility assessments and programs to protect customer profiles. A contractor's role is to convert resources into tangible inventory which is chosen by the client after consultations with all parties involved. Depending on the circumstances, a contractor may work with several subcontractors, each of whom serves a different purpose, such as providing materials, machinery, skilled or unskilled labor, and other necessary items. These distinct supply chain categories are critical in ensuring the overall success of the construction project and, as a result, fostering customer satisfaction [23]. A construction supply chain is a distinct human system that has been meticulously crafted to depict a construction project as an intricate network of numerous interconnected strands linked by economic ties. Thus, supply chain management can be defined as the adept management of strategies, activities, tasks, and processes encompassing a plethora of independent organizational networks and bi-directional communication pathways that bestow value [24].

Supply chain management in the construction industry refers to the intricate process of material flow that begins with suppliers and ends with the end consumer. This dynamic framework emphasizes the interdependence of all stakeholders involved. The costs associated with materials and services cover a wide range of activities, including design, distribution, marketing, and information dissemination. While hierarchical structures and tiers are frequently the result of the economic interdependencies that link each project within the construction endeavor, these arrangements may not always align with the benefits of collaborative pursuits geared toward a common goal [25]. This is not a random occurrence; rather, it is the tangible synchronization of endeavors among its constituents via (communication and control) mechanisms. SCM is fundamentally concerned with the integration of distinct organizational entities along the supply chain continuum. This fusion includes the coordination of material, information, and financial streams to effectively meet the needs of customers. Integration entails critical aspects such as leading supply chain activities, establishing organizational networks, and carefully selecting partners. Coordination also includes aspects such as strategic production planning, strict process orientation, and the implementation of robust information systems [26].

The supply chain transcends singular one-to-one and business-to-business relationships, instead evolving into a complex network of diverse functions and interconnections. Similarly, the supply

chain inherent in the construction project's product development process is typically a multifaceted network of diverse functions and numerous relationships. The management of these relationships is critical to ensuring the quality, cost-effectiveness, and timeliness of products and services. Furthermore, incorporating both customers and suppliers into the product development process becomes critical to ensuring optimal process efficiency. Supply Chain Management provides opportunities for mergers and in-company management alignment. It is critical to recognize in SCM that not all suppliers are equal in importance. To effectively manage the supply chain, priority should be given to selecting primary suppliers. A variety of criteria can be used to select these primary suppliers. Custom engineering or specialized suppliers are frequently the starting points for initial decisions. Nonetheless, a willingness to collaborate as well as a shared objective consciousness are important considerations [27,28].

The primary goal of a supply chain within a construction project, is to assist the project team in optimizing resource utilization and achieving their planning objectives. the result of many studies indicate that SCM practices had improved the overall performance of the construction industry and recognises the importance of adopting the construction industry’s SCM concept. a study done in Algeria with the goal to enhance the industry’s performance strongly indicate that SCM, when integrated with robust relationships, manifests a positive impact on sustainability. The preliminary findings showed a promising trajectory for future investigations into the mechanisms and rationales behind organizations SCM practices [29]. In the United Kingdom, the Latham report [30], emphasises the importance of collaboration among construction stakeholders. supply chain practices such as collaboration and integration were encouraged Ever since the Latham report in the United Kingdom, and made a significant improvement in the construction industry [31,32]. In Australia, [33] indicated that SCM practices had improved the overall performance of the construction industry. This opinion recognises the importance of adopting the construction industry’s SCM concept.

Critical success factors (CSFs) are pivotal elements critical for a system's success; these must be meticulously and consistently taken into account by managers, [34,35] proposes an alternative definition of CSFs as the characteristics, circumstances, or variables that, when properly maintained, managed, or controlled, can significantly impact a company's success within a specific industry. CSFs, facilitated the efficient utilization of limited manpower. However, it is frequently observed that many researchers and practitioners have reported being led astray due to a lack of comprehension of value management and its associated benefits [36]. Since its inception in management literature, CSF has seen widespread adoption by managers across a wide range of management domains, including strategic planning, development, environmental analysis, and strategy evaluation [37,38]. CSF, as a non-partisan instrument, is well-suited for shedding light on issues concerning planning, implementation, improving organizational performance, and tracking progress in organizational activities. The widespread use of CSF in Supply Chain Management (SCM) is due to the universal presence of fundamental success factors across various industries. As a result, every enterprise must acknowledge these factors because they aid in the identification of essential strengths, weaknesses, opportunities, threats, resources, and capabilities [39,40]. This study examines the multifaceted influences of critical success factors within supply chain management, categorizing them into two main domains: hard

and soft factors. Hard factors encompass pressing needs such as meeting contractual obligations, securing short-term gains, and fulfilling project commitments. Specifically, hard factors comprise risk management, information technology infrastructure, and procurement and quality management protocols. Conversely, soft factors stem from relational dynamics, including trust, stakeholder involvement, mutual respect, risk-sharing, effective communication channels, transparency, ethical considerations, and disciplinary mechanisms, which often transcend contractual obligations. This investigation underscores the critical role of soft factors in fostering successful coordination and communication across supply chains. Soft factors include participation and teamwork, effective communication and trust-building practices, leadership endorsement and commitment, organizational culture, customer-centric approaches, and human resources management strategies [41–45].

An examination of the available literature revealed the presence of nine critical recurring success factors relevant to effective supply chain management, as shown in Table 1.

Table 1
Critical success factors of supply chain management.

Factor	Definition	References
Participation and teamwork	Using personal resources to participate in a collective action	[46–50]
Communication and trust	The central process that leads to the exchange of information, the creation of relationships and values, and organizational culture is the expectation that one has of the behavior of another person or group.	[51–56]
Information technology	A combination of skill, knowledge, ability, materials and machine and tools, data explained and interpreted	[53,57–60]
Leadership support and commitment	The extent to which the manager engages with the team to succeed in technology projects	[46,58,61–64]
Culture	Explicit and implicit patterns of human behavior	[65–67]
Customer orientation	Effective and timely responses to customer tastes and preferences	[59,68–71]
Purchase and quality management	Planning, identifying resources, requesting, holding and arbitrating tenders, concluding stages of the contract, execution of the contract and termination of the contract	[58,60,72–74]
Human resources management	Ability to attract, retain and develop talented employees	[47,59,75–77]
Risk management	The process of measuring or evaluating risk and designing strategies for risk management	[58,63,78–81]

Researchers in the field of supply chain management have worked hard to integrate and improve the success of this field. These initiatives incorporate a variety of management paradigms, including lean, agile, sustainable, and green approaches. Table 2 shows a selection of studies used in this study, along with their classifications.

Reviewing the literature reveals that a significant portion of research in the construction supply chain management field has focused on improving supply chain aspects. Recent studies in construction supply chain management should emphasize on soft computing techniques compare to hard computing, especially under uncertain and fast-changing conditions.

Table 2
Summary of research background.

Title	method	Conclusion	Ref.
Supply Chain Management Improvement Through Value Engineering Approach in the Construction Industry	Survey study	Clarify the path to achieving greater productivity in the construction industry by using a combination of two processes of supply chain management and value engineering	[82]
Impact of Power on Financial Performance in Relations between Members of the Supply Chain in Building Industry	Case Study	Direct and significant effect of non-coercive power on trust and commitment in supply chain relationships and inverse and significant effect of coercive power on trust	[83]
Production System Design in Construction	Structural equation	Guidelines for designing project-based production systems	[84]
The impact of logistics performance on organizational performance in a supply chain context	Survey study	Affecting the logistics performance of supply chain management strategy and the positive impact of logistics performance and supply chain management strategy on marketing performance	[85]
Construction Supply Chain Management Evaluation Using an Adaptive Neuro Fuzzy Inference System	simulation	A new agility assessment model for the construction industry supply chain	[86]
Optimization of Main Factors Affecting Construction Waste by the Supply Chain Management	Structural equation	Present four main factors affecting the management of construction waste in Vietnam using fuzzy logic	[87]
Environmental Factors That Affect the Implementation of Green Supply Chain Management in the Construction Industry: A Review Paper	Review study	Identify twelve factors affecting the implementation of GSCM	[88]
A study on factors involved in implementation of supply chain management in the construction industry	Survey study	Suggest solutions to help improve and upgrade contractors' SCM programs	[89]
Literature Review of Areas of Application of Supply Chain Management in Construction Industry	Survey study	All selected SCM research in the eight core areas of procurement, procurement, application of models, information, performance appraisal, customer relationship management, environmental management and sustainability	[90]

Soft computing techniques serve as valuable tools for addressing the dynamic challenges inherent in various parts of the supply chain [91]. Among the soft computing methods classified within machine learning, fuzzy systems, evolutionary computing, probability analysis, and mixed/hybrid approaches, we opted for the fuzzy system method in this research. Fuzzy systems contribute to soft computing by providing a powerful tool for modeling and controlling complex processes and systems based on fuzzy logic, aiming to describe human understanding and inference approaches in mathematical form, thereby offering greater flexibility through assigning true membership degrees when dealing with real-world, nonlinear, and highly complex problems [92]. Fuzzy systems are designed to capture and represent human knowledge and reasoning in a manner that computers can comprehend and utilize for decision-making purposes [93]. The purpose of this research is to use a fuzzy inference system [FIS] to evaluate the efficacy of factors influencing construction supply chain management success rates.

3. Methods

This study aims to assess the success rate of supply chain management using a fuzzy inference system in residential projects in Shiraz-Iran, while also ensuring its adaptability to real-world scenarios. This research aligns with the positivist paradigm, adopting a positivist approach due to its inductive nature, which involves identifying factors and presenting a model based on the fuzzy inference system. Employing a quantitative research approach, this study takes on the form of a case study, as its primary objective revolves around evaluating the success rate of supply chain management within Shiraz's residential construction projects. Examining the research stages elucidates its descriptive-predictive nature, and considering its temporal scope, it qualifies as a cross-sectional study. As illustrated in Figure 1, the initial stage of the research process involves conducting a comprehensive review of prior studies related to the research topic. This step aims to facilitate a deeper investigation and precise formulation of the research problem.

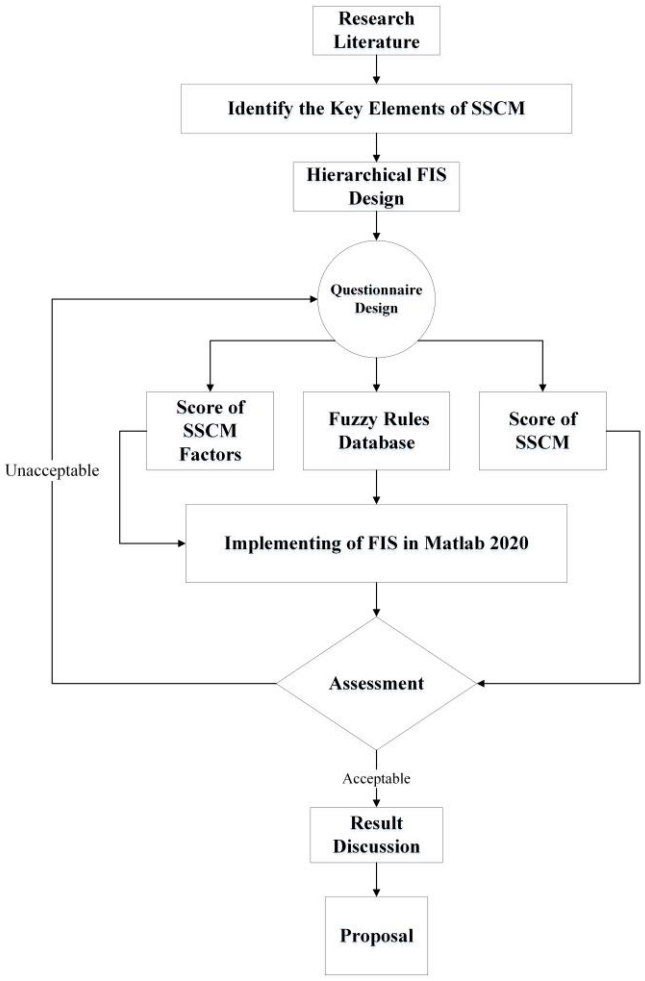


Fig. 1. Research process flowchart.

Subsequently, the fundamental components contributing to the success of construction supply chain management were scrutinized, and their integration resulted in the development of a Fuzzy hierarchical analysis. Moving forward, a questionnaire was meticulously crafted to gather

insights from a panel of experts. In this case, the experts were well-informed about nine critical success factors (CSFs), and we deliberated on the conditions of each CSF that could improve the supply chain conditions for construction projects. For instance, all of the experts concurred that the high rate of inflation in Iran is identified as a significant threat to risk management. This questionnaire consists of three distinct sections: the first pertains to collecting current output values, the second encompasses inquiries designed to construct a database of fuzzy rules, and the final section focuses on obtaining preliminary values for key success elements. In the subsequent phase, the fuzzy inference system was executed within the MATLAB software environment, and the ensuing outcomes underwent comprehensive evaluation. If the results did not meet acceptable criteria, experts were consulted for additional input. Conversely, if the outcomes were deemed acceptable, progression was made to subsequent stages, encompassing outcome analysis and presentation of findings.

3.1 Fuzzy inference system

The probability measure system recognized as fuzzy logic, drawing from the cognitive prowess of human thinking, consists of a set of rules and an activation function. Fuzzy logic functions within a multi-valued framework, accounting for degrees of membership and degrees of truth, in contrast to the binary characteristic of two-valued Boolean logic. As emphasized by Zadeh, fuzzy logic operates along a spectrum of logical values, spanning from 0 (completely false) to 1 (completely true) [94]. This evolution within the realm of possibility theory, facilitated through fuzzy logic, empowers the depiction and manipulation of ambiguous concepts through the utilization of natural language terms. In this study, the employment of the fuzzy method is necessitated by the absence of precise information concerning inter-variable relationships linked to pivotal factors. Concurrently, the fuzzy inference system emerges as a formidable tool for scenarios reliant on expert opinions. Functioning as a knowledge-driven system, the fuzzy inference system facilitates the incorporation of expert experience and expertise. In cases where comprehensive and precise information regarding the phenomenon under study is unavailable, analyzing the behavioral patterns of said phenomena can be accomplished through the utilization of fuzzy logic and the design of a fuzzy inference system that is the same as a black box, which connects the input space to the output space through some fuzzy if-then rules. A fuzzy if-then rule can be shown as follows:

if x is A then y is B; [95]

This input was captured in the form of a set of fuzzy rules, subsequently serving as the basis for making inferences [96]. In classical set theory, the membership of element X in set A expresses with binary values of either zero or one. However, within the realm of fuzzy science, the membership of X in set A is characterized by a numerical value spanning the range from zero to one. In the domain of fuzzy management science, the decision-making process in an uncertain environment involves the utilization of degrees of confidence in tested hypotheses. This process entails the design of a decision support system that considers these degrees of confidence [97,98]. Fuzzy inference systems are typically proposed using two primary methods: The Mamdani method or the Sugeno-Takagi method. For this research, the Mamdani method has been employed which encompasses is composed of four functional components [94]:

Fuzzification module: This module employs a fuzzification function to convert precise input values into corresponding fuzzy sets.

Knowledge base: The knowledge base serves as a repository for IF-THEN rules furnished by experts.

Inference engine: Functioning akin to human reasoning, the inference engine employs the provided inputs and IF-THEN rules to carry out fuzzy inferences.

Defuzzification module: Following inference, the defuzzification module transforms the resulting fuzzy set from the inference engine into a precise numerical value.

The main stages of the Mamdani fuzzy method are shown in figure 2.

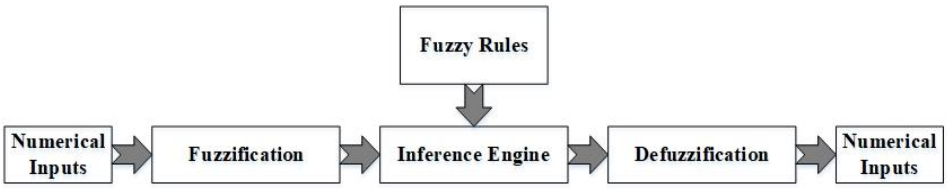


Fig. 2. The main stages of Mamdani fuzzy method.

The initial phase involves establishing fuzzy membership functions for fuzzy input and output variables. These functions encapsulate the perspectives of experts, manifesting as membership functions, table 3, for inputs denoted by fuzzy triangular numbers and linguistic variables (e.g., weak, middle-aged), and for outputs expressed in fuzzy triangular numbers corresponding to linguistic variables (e.g., very weak, weak, medium, good, and very good). Following the independent definition of fuzzy if-then rules, a constraint is applied to map each rule to the system based on its accuracy level. The if–then rules establish links between input membership functions and their corresponding output membership functions. In these rules, the "if" part serves as the antecedent, specifying the membership function for each input linguistic variable, while the "then" part indicates the consequence, defining the membership function for each output linguistic variable. For instance, these following statements is a part of the questionnaire which indicate the fuzzy rules to design success factors fuzzy block (FIS-5), as outlined by one of the experts.

1. If (soft factors is Low) and (hard factors is Low) then (success factors is very low).
2. If (soft factors is Low) and (hard factors is Medium) then (success factors is low).
3. If (soft factors is Low) and (hard factors is High) then (success factors is Medium).
4. If (soft factors is Medium) and (hard factors is Low) then (success factors is Medium).
5. If (soft factors is Medium) and (hard factors is Medium) then (success factors is High).
6. If (soft factors is Medium) and (hard factors is High) then (success factors is Very High).
7. If (soft factors is High) and (hard factors is Low) then (success factors is low).
8. If (soft factors is High) and (hard factors is Medium) then (success factors is Medium).
9. If (soft factors is High) and (hard factors is High) then (success factors is Very High).

In the context of the Mamdani fuzzy inference system, a precision degree (implication) is assigned to each of the fuzzy functions. This precision degree can adopt the minimum torque

(MM) or the torque multiplier (MP), with the former being utilized as the minimum within this context. To integrate the rules, two approaches can be employed: the max method and the sum method. In this specific model, the maximum method has been adopted [97]. Upon amalgamating the rules and acquiring the output results, a range of methods is available for breaking down the system's outputs. Within these approaches, several noteworthy options exist, including the half-maximum, bisector, center of gravity, average value of maximum output set, largest maximum (LOM), and smallest maximum (SOM) methods [99]. Once an appropriate fuzzy spectrum is chosen and the corresponding fuzzy operation is executed, the outcome naturally adopts a fuzzy format. However, these fuzzy outcomes pose challenges in terms of comprehension and interpretation, necessitating their conversion into conventional numerical values. This conversion process, referred to as de-fuzzing, is undertaken to yield precise numbers. In the subsequent phase, aimed at obtaining a definitive output, the center of gravity method, equation 1, is employed within this study.

$$\mathrm{COG}=\frac{\int_a^b \mu_A(X).X\,dx}{\int_a^b \mu_A(X)\,dx} \tag{1}$$

The linguistic variables designated to each fuzzy set corresponding to inputs based on the assessment of experts consist of "Low," "Medium," and "High." Similarly, concerning the outputs, the linguistic variables encompass "Very Low," "Low," "Medium," "High," and "Very High" as outlined in Table 3.

Table 3
Membership functions of input and output variables.

	Linguistic variables	Symbol	fuzzy numbers
Input variables	Low	L	[0 , 0 , 0.5]
	Medium	M	[0 , 0.5 ,1]
	High	H	[0.5 , 1 , 1]
Output variables	very low	VL	[0 , 0 , 0.25]
	Low	L	[0 , 0.25 , 0.5]
	Medium	M	[0.25 , 0.5 , 0.75]
	High	H	[0.5 , 0.75 , 1]
	very high	VH	[0.75 , 1 , 1]

3.2 Validity and validation of the questionnaire

In this study, the initial stage for determining content validity involved preparing a questionnaire subsequent to an extensive review of the literature and theoretical underpinnings. This questionnaire was then distributed among experts, table 4, in the pertinent field, who provided their insights and suggestions. The objective was to assess whether the initial values were accurately incorporated as inputs and if the desired fuzzy rules for the organization were adequately captured. Employing this strategy between expert opinions and the output generated by the fuzzy inference system, a measure of validity was established. The outcome indicated that the questionnaires possessed robust validity. Furthermore, for model validation, various error metrics were employed including Mean Squared Error (MSE), Root Mean Squared Error (RMSE), and Mean Absolute Percentage Error (MAPE). These errors were computed and juxtaposed against the fuzzy expert system's output. The recorded error values were as follows from left to right: 0.00071, 0.0008, and 0.00003. The values collectively emphasize the

acceptable margin of error within the system, thereby endorsing the effectiveness of the designed system. The errors validated by the model demonstrate satisfactory validity, as they are less than half the distance between the two output results {<0.25/2=0.125} [100].

Table 4
Characteristics of experts.

No	SEX	Age	Job	work experience (year)
1	Male	39	Project Manager	15 years
2	Male	40	Project Manager	10 years
3	Male	36	Project Manager	12 years
4	Male	41	Project Manager	14 years
5	Male	35	Project Manager	8 years
6	Male	40	Project Manager	10 years
7	Male	39	Project Manager	14 years
8	Male	42	Project Manager	10 years

3.3 Hierarchical FIS

An inherent challenge within the fuzzy inference system method is the potential for an overwhelming proliferation of fuzzy rules, colloquially referred to as "rule explosion." To mitigate this issue, a hierarchical FIS is employed to manage the count of fuzzy rules. The number of fuzzy rules for each FIS system is calculated in Equation 2. In this equation N represents the number of rules, M represents the number of fuzzy sets for inputs (in this study is 3 {Low, Medium, High}), and V represents the number of input variables for every FIS engine/block.

$$N = M^V \tag{2}$$

In this particular study, 9 distinct success factors have been identified, a scenario that could yield an immense 3^9= 19683 fuzzy rules that are improbable to be answered by experts. To address this issue, a dual input layer approach is adopted, and the tally of fuzzy rules is delineated in Figure 3. In the proposed Hierarchical FIS model, we minimized the number of rules to 99, as demonstrated by Equation 3.

$$3^2 + 3^2 + 3^3 + 3^3 + 3^3 = 99 \tag{3}$$

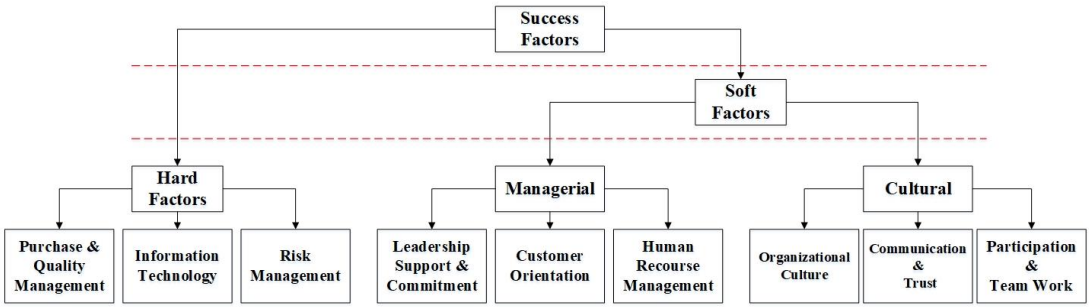


Fig. 3. Hierarchical FIS.

4. Results

As indicated in Table 5, the initial values, derived from expert opinions, are presented. Within this table, all factors contributing to the success of supply chain management are assigned values

within the range of 0 to 1. Correspondingly, anticipated output scenarios within the 0 to 100 range for the organization's supply chain management have been generated based on insights provided by experts.

Table 5
Initial values of expert opinions.

No	Input	Expert 1	Expert 2	Expert 3	Expert 4	Expert 5	Expert 6	Expert 7	Expert 8	Average
1	Participation and teamwork	70	40	45	50	45	50	30	60	48
2	Organizational Culture	90	55	50	45	60	45	50	45	55
3	Communication and trust	75	45	40	55	35	55	50	30	48
4	Leadership Support and Commitment	85	60	55	45	45	60	35	60	55
5	Customer Orientation	60	20	35	50	55	50	45	55	46
6	Human resources management	70	30	40	60	70	65	50	60	55
7	Purchase and quality management	70	30	55	55	50	45	50	55	51
8	Information Technology	85	50	60	50	45	60	55	70	59
9	risk management	50	20	30	45	35	40	55	30	38
10	Construction supply chain management	75	45	55	50	50	45	60	55	54

Based on the input values and the rules defined, the accepted fuzzy inference system blocks by experts are depicted in Figure 4, which indicates the results of these computations. Figure 4 depicts snapshots of the results obtained from the analysis conducted in MATLAB. Figure 4 showcases the rule viewer, which is a read-only tool displaying the complete fuzzy inference diagram, encompassing fuzzy implication, fuzzy aggregation, and defuzzification.

These calculations arise from the initial input values and the output of each block which is illustrated in Figure 5. The subsequent fuzzy block's title is determined accordingly, thus forming the fuzzy rule set. This fuzzy rule set contributes to constructing a hierarchical FIS, where the output aligns of hierarchical FIS with the overall output (representing the success rate of supply chain management). As depicted in Figure 5, the proposed hierarchical Fuzzy Inference System (FIS) comprises 5 distinct fuzzy inference systems. FIS 1, 2, and 4 consist of three inputs each, resulting in a total of $3^3 = 27$ fuzzy rules for each respective FIS. On the other hand, FIS 3 and 5 contain $3^2 = 9$ rules each. The inputs of FIS 3 are derived from the outputs of systems 1 and 2, while the inputs of FIS 5 are reliant on the outputs of systems 3 and 4. The system is methodically structured, where each FIS is initially defined, specifying their respective inputs and outputs. Subsequently, the incorporation of fuzzy rules takes place. Following this, the systems are interconnected within the framework of an integrated fuzzy structure, subsequently preceding the subsequent analysis. The following illustrates Algorithm 1: Pseudocode for a cohesive hierarchical FIS.

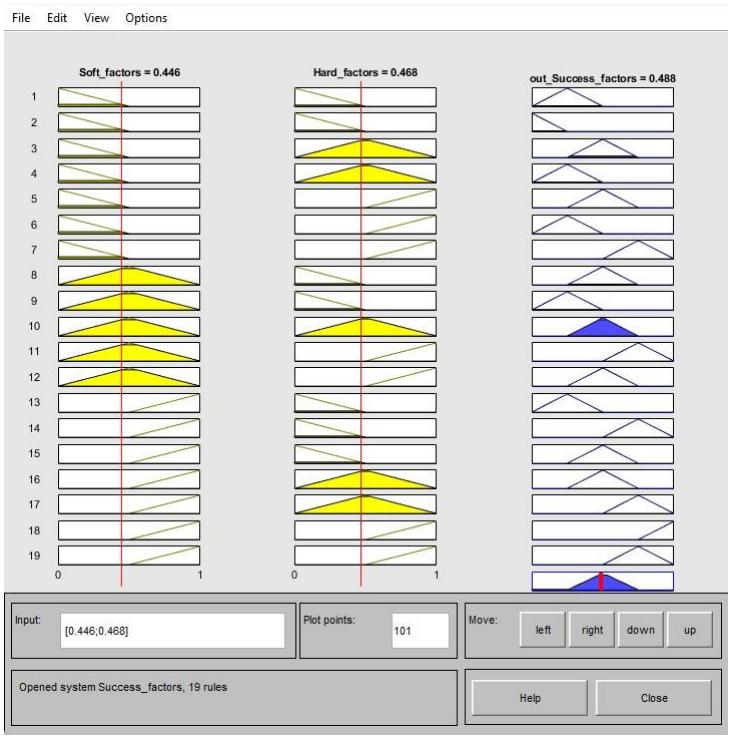


Fig. 4. Rule viewer (view of input and output parameters).

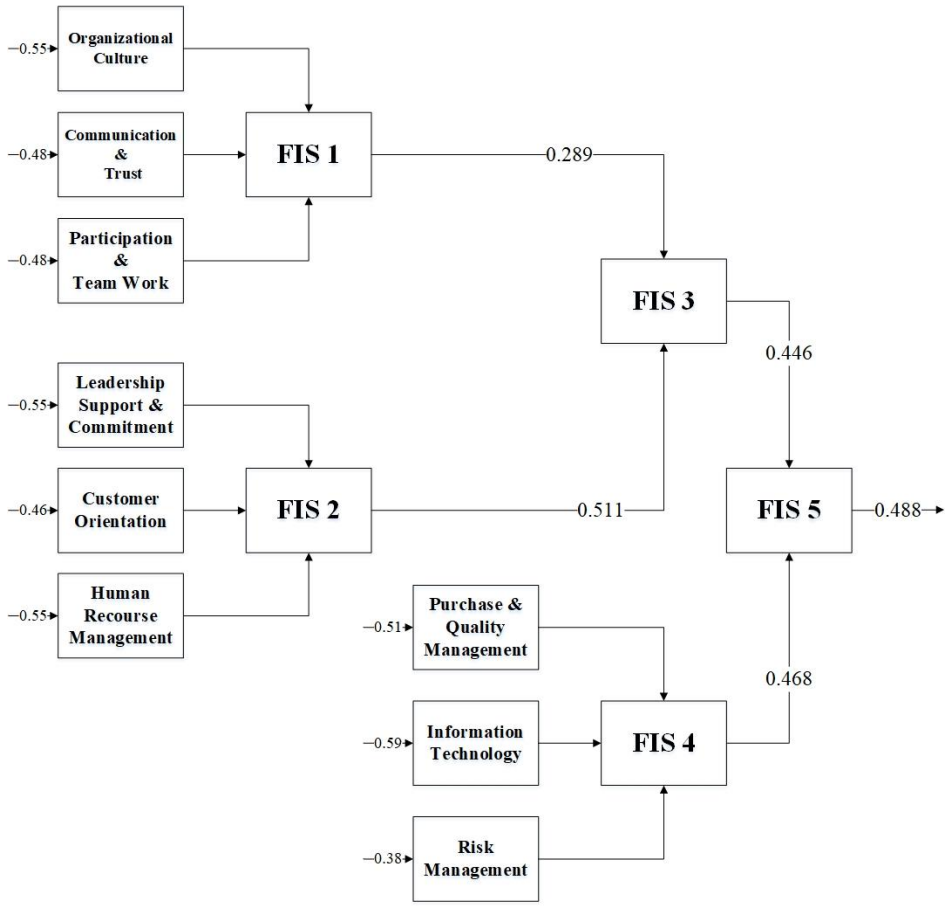


Fig. 5. Computation of hierarchical FIS.

Algorithm 1: Pseudo code for a cohesive hierarchical FIS

Input: (P1, P2, P3, ..., P9)

Output: (SOSCM[1])

Begin:

I: FIS_1 (P1, P2, P3) {

- μ (P1)// change the numeric input value P1 to fuzzy value
- μ (P2)// change the numeric input value P2 to fuzzy value
- μ (P3)// change the numeric input value P3 to fuzzy value

for j ← 1 to 27 do

- Rule inferencing
- μ (zj)// implication of rules

od

- μ (y1) ← Aggregate (): // Aggregation

fuzzy rules integration

out_1- ← μ (y1) Defuzzification

} II: FIS_2 (P4, P5, P6) {

- μ (P4)// change the numeric input value P4 to fuzzy value
- μ (P5)// change the numeric input value P5 to fuzzy value
- μ (P6)// change the numeric input value P6 to fuzzy value

for j ← 1 to 27 do

- Rule inferencing
- μ (zj)// implication of rules

od

- μ (y2) ← Aggregate (): // Aggregation

fuzzy rules integration

out_2- ← μ (y2) Defuzzification

} III: FIS_3 (out_1, out_2) {

- μ (out_1)// change the numeric input value out_1 to fuzzy value

[1] Success of supply chain management

- μ (out_2)// change the numeric input value out_2 to fuzzy value

for j ← 1 to 9 do

- Rule inferencing
- μ (zj)// implication of rules

od

- μ (y3) ← Aggregate (): // Aggregation

fuzzy rules integration

out_3- ← μ (y3) Defuzzification

} IV: FIS_2 (P7, P8, P9) {

- μ (P4)// change the numeric input value P7 to fuzzy value
- μ (P5)// change the numeric input value P8 to fuzzy value
- μ (P6)// change the numeric input value P9 to fuzzy value

for j ← 1 to 27 do

- Rule inferencing
- μ (zj)// implication of rules

od

- μ (y4) ← Aggregate (): // Aggregation

fuzzy rules integration

out_4- ← μ (y4) Defuzzification

} V: FIS_5 (out_3, out_4) {

- μ (out_3)// change the numeric input value out_3 to fuzzy value
- μ (out_4)// change the numeric input value out_4 to fuzzy value

for j ← 1 to 9 do

- Rule inferencing
- μ (zj)// implication of rules

od

- μ (y5) ← Aggregate (): // Aggregation

fuzzy rules integration

out_5- ← μ (y5) Defuzzification

} **End**

In the analysis of Figure 6, encompassing cultural factors, it can be observed that from the initial point to approximately 0.18, the rate of enhancement in cultural factors remains constant compared to all three elements of organizational culture, participation, carte blanche, communication, and trust. Within this range, no discernible progress is evident. It can be deduced that investors must bear a certain amount of responsibility and continue their investment efforts. From 0.2 to 0.5 on all three diagrams, a marked negative slope is apparent. This phenomenon can be attributed to the interconnection between these three factors and the individual's personality and mindset.

While some argue that an emphasis on cultural factors could always improve outcomes, many experts contend that such an approach yields long-term benefits rather than immediate results, potentially resulting in wasted time and resources. They argue that shifting cultural mindsets is intricate and often met with initial resistance, leading to counterproductive outcomes. However, a noticeable positive trend emerges from a value of 0.5 onwards in the chart, indicating the value of investing in cultural factors as the chart progresses. This trend is also evident in the three-dimensional representations of these factors.

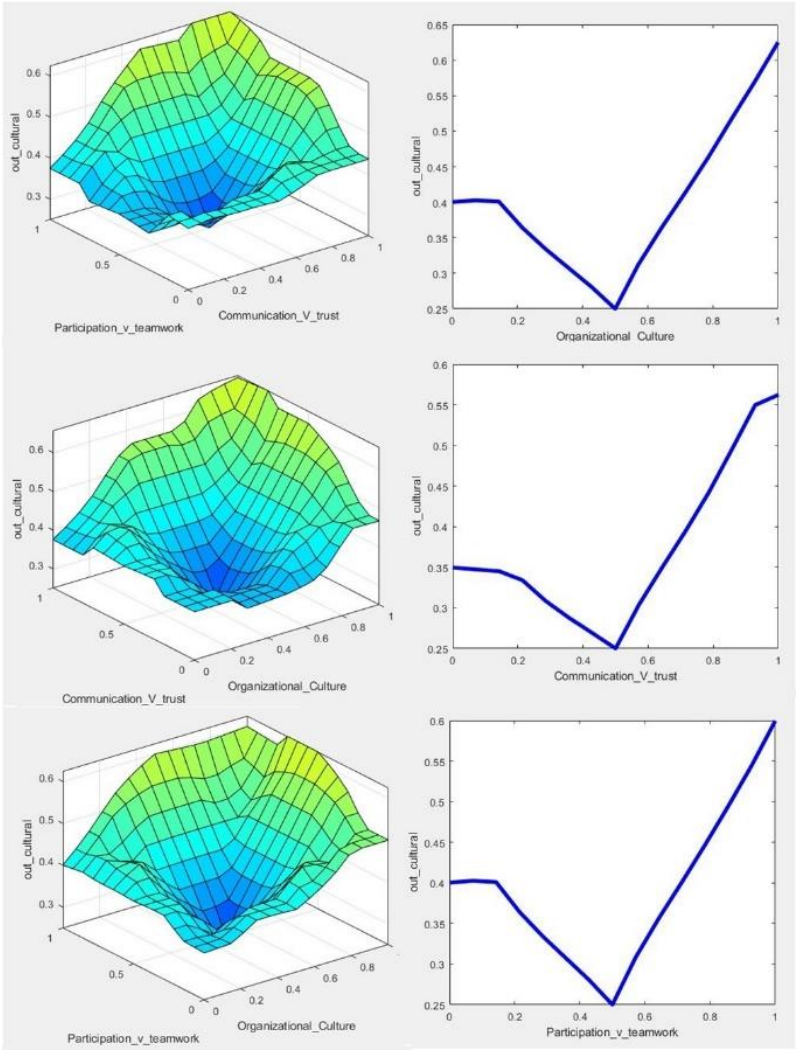


Fig. 6. Cultural factors.

In Figure 7, featuring management group charts, human resource management, and customer-oriented charts, improvements in the management factor are evident from the outset to the conclusion. Although the increments are modest initially, the chart's slope gradually steepens over time. The rate of enhancement accelerates, and while it tapers at the chart's end, the improvement continues. Turning to the leadership support and commitment chart, an initial horizontal value of approximately 0.18 is noticeable. Subsequently, the chart's slope sharpens, leading to a significant acceleration in the rate of improvement. Although the slope slightly reduces afterward, the progress does not halt completely. The outcomes of this analysis underscore the viability of investing in these factors. This analytical trend is also evident in the three-dimensional depictions of the factors.

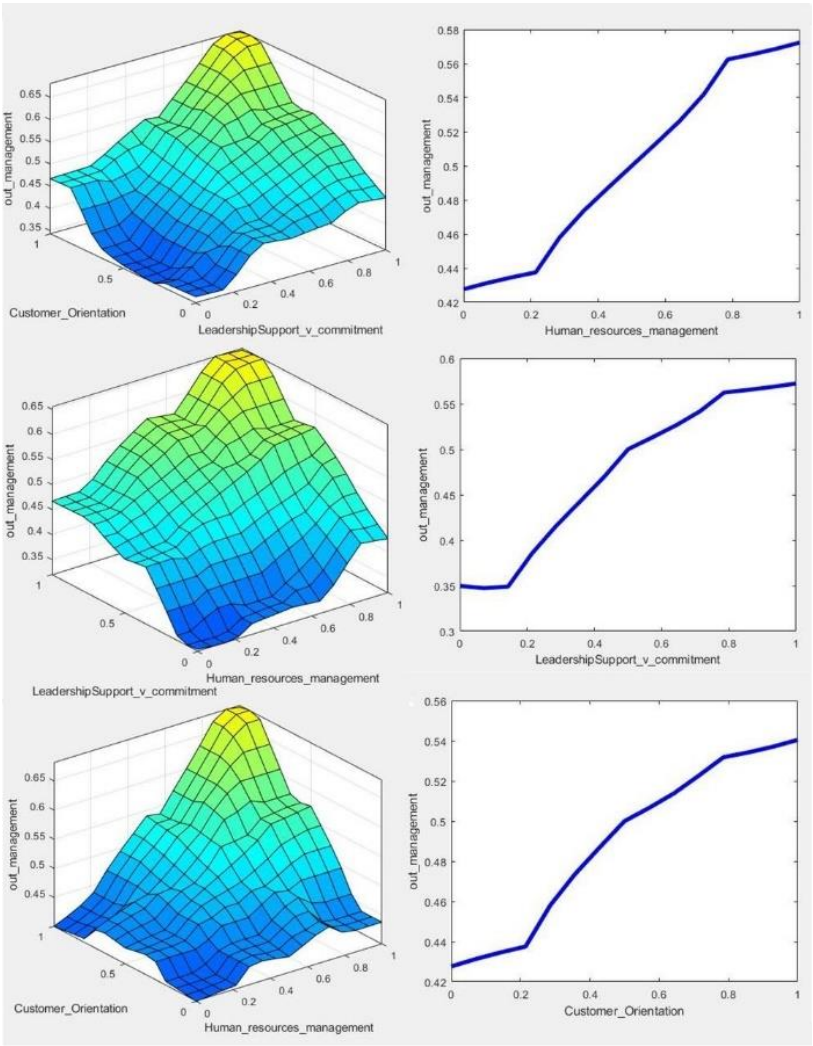


Fig. 7. Management factors.

Analyzing Figure 8 reveals that all challenging factors, encompassing risk management, purchasing, quality management, and information technology, contribute to the eventual enhancement of challenging aspects. At the initial stage of the chart, a consistent pattern is observed up to the point of 0.18. Beyond this juncture, a marked steepening in the chart's slope becomes apparent, indicating that investment in these factors might not yield immediate

progress. Initial efforts may require endurance, yet substantial advancement becomes evident subsequently. Towards the chart's conclusion, although the rate of progress slightly diminishes, it remains continuous. This implies that these factors warrant investment due to their capacity for sustained growth. This analytical assessment is also discernible within the three-dimensional depictions of these factors.

According to Figure 9, both soft and hard factors contribute to the success of supply chain management. Soft factors exhibit an increasing trend from the chart's initiation to its conclusion. Although there are slight decreases in the slope at the outset and end of the chart, the overall upward trajectory remains consistent, advocating for investments in this aspect. In contrast, the hard factor displays an ascending pattern during the initial and middle portions of the chart. Investments in this factor positively impact supply chain management. However, towards the chart's end, the upward momentum halts. Additional investment yields no discernible results and fails to further enhance supply chain management. This analysis is also discernible within the three-dimensional depiction of these factors.

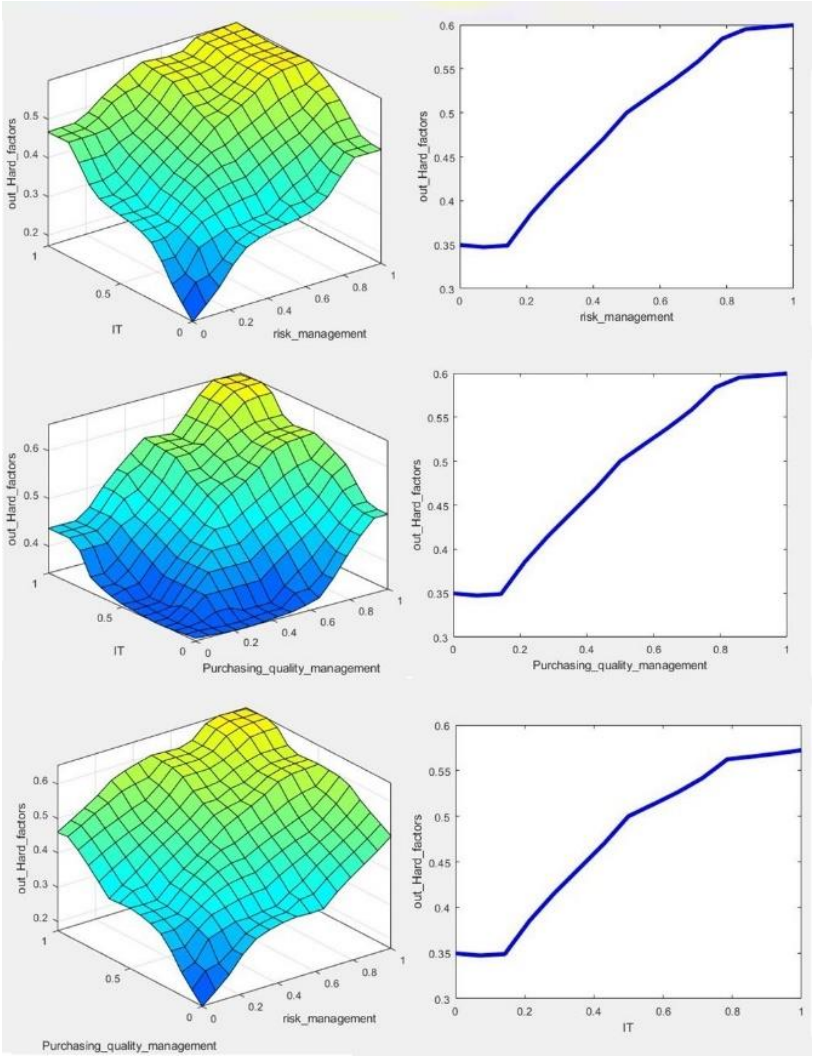


Fig. 8. Hard factors.

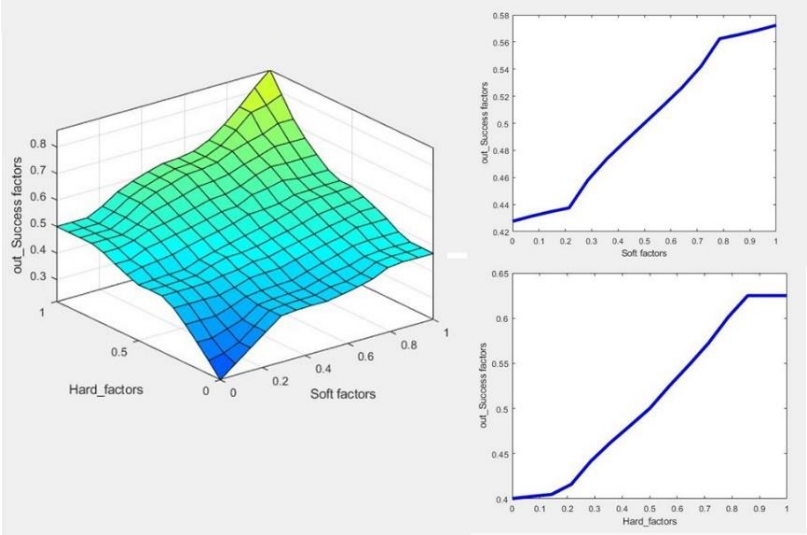


Fig. 9. Success factor.

5. Conclusions

According to the feasibility study, utilizing this method could offer experts deeper insights, as understanding linguistic variables enables a more accurate simulation of their responses. In contrast, the empirical analysis provides only superficial scores for factors [101,102] compared to the fuzzy model, which adeptly addresses ambiguous and imprecise language. Based on the research findings, hard factors have the greatest and continuous influence on the success of construction supply chain management. An increase in hard factors correlates with improved supply chain management success. within the hard factors, risk management was emphasized as a critical aspect, similar to the importance of purchase and quality management execution. Implementing risk management will improve project performance by ensuring the achievement of project objectives as well as the exploration of opportunities that can have a greater positive impact on these objectives [103]. The identification and assessment of project risks is a critical project management process, and it can be concluded that the level of risk has a direct impact on success and execution in the construction industry. Regarding the aspects of construction projects, the significance of risks, the prevalent risk management techniques, the current state of risk management systems within organizations, and the barriers to effective risk management as perceived by key stakeholders. Notably, financial and economic factors emerge as the most critical risks, closely followed by quality considerations. In the context of stable economic conditions, the determination of construction project costs presents a manageable task. However, amidst the dominant uncertainties in costs and the dynamic economic and financial landscape of Iran [104], the imperative for robust risk management becomes evident. Efforts are being made across the industry to avoid or transfer these risks [105].

Resource sharing can serve as a strategic response to mitigate the impact of supply chain disruptions on an organization. Collaborative resource sharing, both within the organization itself (intra-organizational) and with partner organizations (inter-organizational), can lead to the creation of value for all entities involved while concurrently reducing the risk associated with

construction project performance [106]. Buffer management can effectively address uncertainties that disrupt project planning and scheduling, specifically those associated with activity time uncertainty, path time uncertainty, and resource uncertainties [107]. Ineffectual purchasing and quality management practices are not limited to internal organizational aspects but are notably conspicuous in the management of suppliers and subcontractors. A significant number of construction accidents stem from subpar materials or the inexperience of subcontractors. It is essential to recognize that material suppliers and subcontractors hold pivotal positions within the construction supply chain, and their selection and management are foundational in guaranteeing project quality [108]. Establishing trust in quality management within the construction supply chain is of utmost importance, as it enhances work efficiency and employee safety within construction companies. The integration of quality management and supply chain practices contributes significantly to fostering balanced growth within the construction industry [109].

In terms of soft factors, which include cultural and managerial components, cultural factors have an apparent impact in the short-term. However, in the long run, managerial factors become more prominent and influential, contributing significantly to the development of soft factors. Communication and trust emerge as the most powerful cultural factors, specifically related to the issue of trust [110], emphasizing their critical importance. The absence of genuine collaboration, cooperative working relationships, and trust among parties in supply chains, associated with a reluctance to share risks and benefits, can be attributed to a confrontational culture and adversarial behavior among the involved parties. This uncooperative attitude and adversarial dynamics often lead to a multitude of wasteful practices. Historically, contracts between parties have been rigid and lacked an emphasis on cooperation and the equitable distribution of risks and benefits. This focus on individual responsibilities creates a significant barrier between parties. In the course of project collaboration, parties tend to prioritize their interests at the expense of cooperative efforts with other stakeholders [111].

The concept of trust, according to [112], facilitates delegation of authority and acceptance of uncertainties. Building trust requires a foundation of familiarity and security. This foundation fosters confidence through repeated interactions, which is especially important in the presence of uncertainties. The customer-oriented factor emerges as the most impactful in the context of management factors in the short term. This factor helps to increase value and reduce costs.

Long-term human resource management factors [113,114] highlight the importance of skill and knowledge development. They also emphasize the significance of instituting a system of rewards, punishments, and discipline. Senior leadership's support and commitment, as well as factors such as the reward system, quality management, and effective leadership, all play important roles [52]. Outstanding leadership support is a critical factor in project success. This level of assistance helps to improve the project team's performance and capabilities. Many experts stress the importance of risk management. Construction projects, are fraught with numerous risks that have the potential to significantly disrupt the supply chain. These risks are dependent on several factors and necessitate skilled management to ensure the success of the construction supply chain [115]. In contrast to prior investigations that focused on the correlation between CFS in SCM outcomes and identified success factors and barriers [116], this study aims

to assess and determine the specific sub-criteria where investment is most strategically sound, considering both short-term and long-term benefits.

6. Study limitations

The current study, like other research endeavors, has its own set of limitations, which are discussed in this paper. The proposed approach based on the fuzzy inference system is a sophisticated methodology that requires experts who are well-versed in the tenets of fuzzy logic as well as the complexities of the developed mental models of the supply chain management process. The experts' weights were uniformly considered in this study, regardless of variations in their expertise, which may differ in practice. Recognizing and differentiating these disparities for weight allocation is critical.

The fuzzy membership functions used in this study were chosen based on previous similar studies, without consulting experts. It's worth noting that this study was conducted in Shiraz and is cross-sectional in nature. As a result, caution should be exercised when extrapolating the findings to broader contexts.

Our recommendations for future research are as follows:

- Expert Weight Allocation Refinement: Future researchers should investigate the characteristics of experts' professional competencies related to the study subject for more precise results in similar studies. To assign appropriate weights to each expert, multi-criteria decision-making techniques such as network analysis, which accounts for the interrelationships among criteria, could be used.
- Increasing the Number of Fuzzy Language Variables: Variable functions in fuzzy languages can be interpreted in a variety of ways or modes. Future research endeavors can investigate changing the linguistic states of variables and introducing additional linguistic variables into the model to ensure greater flexibility and accuracy. As a result, the system's overall behavior will be more in line with the reality it seeks to simulate.
- Improving Fuzzy Membership Functions: Future studies could use methods such as the modified horizontal approach to generate fuzzy membership functions for linguistic data collection. This method aids in ensuring that the information gathered resonates more harmoniously with the linguistic expressions used by the study's experts.
- Integrating System Dynamics and Fuzzy Inference: Researchers could consider combining the fuzzy inference system method with system dynamics to account for feedback relationships between variables. This integration can provide a more complete picture of how variables interact with and influence one another within the system.
- Future researchers can enhance the proposed model by incorporating these suggestions, resulting in more accurate and comprehensive results in similar studies.

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Conflicts of interest

The authors declare no conflict of interest.

Authors' contribution statement

AHP, AF: Conceptualization; MN: Formal analysis; AHP: Investigation, SS; AHP, AF, MN: Methodology; AHP, MN: Software; AF: Supervision; AF, SS: Validation; MN: Visualization; AHP, AF: Roles/Writing – original draft; AF, MN, SS: Writing – review & editing. All authors have read and agreed to the published version of the manuscript.

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