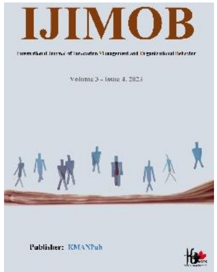
Journal Website

Article history:
Received 26 August 2023
Accepted 26 November 2023
Published online 01 December 2023

International Journal of Innovation Management and Organizational Behavior

Volume 3, Issue 4, pp 209-218



E-ISSN: 3041-8992

Design of a Fuzzy Expert System for Organizational Performance and Innovation Evaluation Based on the Role of Knowledge Management and Intellectual Capital

Zohreh. Toozandehjani[1], Jalal. Rezaee Noor[2]*, Mirfeiz. Falah Shams[3]

[1] PhD Student in Information Technology Management, Department of Management, Qom Branch, Islamic Azad University, Qom, Iran
[2] Associate Professor, Department of Industrial Engineering, Qom University, Qom, Iran
[3] Assistant Professor, Department of Business Administration, Central Tehran Branch, Islamic Azad University, Tehran, Iran

*** Corresponding author email address**: J.rezaee@qom.ac.ir

A r t i c l e I n f o

Article type:
Original Research

How to cite this article:
Toozandehjani, Z., Rezaee Noor, J., & Falah Shams, M. (2023). Design of a Fuzzy Expert System for Organizational Performance and Innovation Evaluation Based on the Role of Knowledge Management and Intellectual Capital. *International Journal of Innovation Management and Organizational Behavior*, *3*(4), 209-218.
https://doi.org/10.61838/kman.ijimob.3.4.24

A B S T R A C T

Objective: This study aimed to evaluate organizational performance and innovation based on the role of knowledge management and intellectual capital.

Methodology: This study was conducted using a qualitative approach (interviews with experts). Through expert interviews and grounded theory, research criteria including causal conditions, intervening factors, strategies, and outcomes were derived. The criteria and sub-criteria were then ranked using the fuzzy Analytical Hierarchy Process (AHP) method. Causal factors and strategies were used as inputs to the model, while outcomes were treated as output variables. The expert system in this study had two inputs and one output. For the input sub-criteria, rules were defined based on expert opinions, and fuzzy inference was performed. The outputs of the expert system were the sub-criteria of the outcomes, which included five variables, and the fuzzy section utilized MATLAB software.

Findings: Among the identified factors, causal factors were found to be more important than contextual and intervening factors. Within the causal factors, social factors were of greater significance. In the strategies category, human resources were identified as the most important, and ultimately, organizational outcomes were considered the most significant results.

Conclusion: Overall, it can be stated that evaluating organizational performance and innovation based on the role of knowledge management and intellectual capital is of great importance. The utilization of a fuzzy expert system approach in this context can significantly assist managers and decision-makers in assessing organizational performance and innovation.

Keywords: *Knowledge Management, Intellectual Capital, Organizational Performance, Organizational Innovation, Fuzzy Expert*

1 Introduction

Today, with the increasing complexity of competition, innovation is considered one of the main advantages for the survival of companies. All organizations need new and creative ideas to survive. New and creative ideas are like a soul breathed into the body of an organization, saving it from demise and extinction (Du Plessis, 2007). The emergence of knowledge innovation not only enables organizations to gain a competitive advantage over their rivals but also provides a useful tool for enhancing organizational performance (Dickel & de Moura, 2016). Knowledge, as a major source for organizational innovation and productivity, is of immense importance (Darroch, 2005). Hence, knowledge management is often recognized as the main source and reference for innovation and is considered a fundamental requirement in the innovation process within organizations. New knowledge enables organizations to improve their performance, develop their capabilities, and more effectively utilize existing resources (Sedziuviene & Vveinhardt, 2010).

Intellectual capital is a collection of knowledge, information, intellectual assets, experience, competition, and organizational learning that can be employed to create wealth (Donate & de Pablo, 2015; Donate & Guadamillas, 2011). In fact, intellectual capital encompasses all employees, organizational knowledge, and its capabilities to create added value, leading to sustained competitive advantages (Al-Hakim & Hassan, 2016). Intellectual capital is an intangible asset that serves as a competitive advantage for organizations and can increase the company's market share through knowledge and information (Rehman & Iqbal, 2020).

In accounting, intellectual capital refers to assets that lack physical properties but fundamentally offer significant benefits for the future cash flow of companies. Intellectual capital is the sole competitive advantage of companies. However, financial reports lack relevant information about these valuable resources. Economic wealth is increasingly driven by the process of producing knowledge and information (Singh et al., 2021). In the past, the economy relied on natural resources, equipment, and capital to create value, whereas today's economy depends on knowledge and information (Iqbal et al., 2021). Organizational performance measurement requires systematic and structured tools and frameworks. One of the modern methods for evaluating organizational performance is the Balanced Scorecard, which evaluates non-financial as well as financial components and aims to assess all aspects and dimensions influencing the company by creating a four-fold framework that evaluates elements such as finance, growth and learning, customers, and internal processes (Donate & Guadamillas, 2011). Given the importance of evaluating organizational performance and innovation, the objective of this study was to design a fuzzy expert system to evaluate organizational performance and innovation based on the role of knowledge management and intellectual capital.

2 Methods and Materials

This research is applied in nature, descriptive in type, and employs quantitative grounded theory to present the conceptual model of the study. The primary data sources in this research were interviews, and after each interview, coding was conducted on the interview data. Through constant comparison of the data, theoretical codes emerged through open coding, and 15 interviews were coded in this manner, resulting in the emergence of concepts and subcategories. The statistical population consisted of 15 software industry experts. Ultimately, from the identified codes and components, 132 key concepts, 37 subcategories, and 5 main categories were extracted from the interviews and compiled into a grounded conceptual model. For screening and ensuring the importance of identified indicators and selecting final indicators, the fuzzy Delphi method was used. To assess the importance of the indicators from the experts' perspectives and to fuzzify their views, triangular fuzzy numbers were utilized, and expert opinions regarding the importance of each indicator were gathered using a 7-level fuzzy scale. After two rounds of the Delphi technique, no question was eliminated in the second round, indicating the conclusion of the Delphi rounds. Generally, one approach to concluding Delphi is to compare the average scores of the questions from the last two rounds. If the difference between the two stages is significantly smaller than the threshold, the survey process is stopped. According to the results obtained, it was determined that in all cases, the difference was less than 2. Therefore, the Delphi rounds could be concluded. Based on the output of grounded data analysis, five main factors and a total of 13 main sub-criteria were identified. In the second step of this research, the Analytic Hierarchy Process (AHP) technique was employed to determine the weights of the criteria and indicators of the model.

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E-ISSN: 3041-8992

3 Findings and Results

The hierarchical structure of the criteria and sub-criteria of the model using the AHP technique is outlined in Table 1.

Table 1

Research Criteria and Sub-Criteria

Symbol	Main Criteria	Sub-Criteria	Symbol
C1	Causal Factors	Individual Factors	S11
		Organizational Factors	S12
		Social Factors	S13
C2	Contextual Factors	Organizational Contexts	S21
		Managerial Contexts	S22
C3	Intervening Factors	Organizational Factors	S31
		Supra-Organizational Factors	S32
C4	Strategies	Human Resources Strategies	S41
		Managerial Strategies	S42
		Social Strategies	S43
C5	Outcomes	Individual Outcomes	S51
		Organizational Outcomes	S52
		Social Outcomes	S53

To determine the priority of the identified indicators, the Fuzzy Analytic Hierarchy Process (FAHP) technique was employed. In the first step, the main criteria were pairwise compared based on the objective. Ten pairwise comparisons were performed from the perspective of a group of experts, and their opinions were quantified using a fuzzy scale. To aggregate expert opinions, it was preferable to use the geometric mean of each of the three triangular fuzzy numbers. The pairwise comparison matrix was constructed based on the fuzzy geometric mean of the experts' opinions, and this matrix, denoted as $\bar{X}$, is presented in Table 2.

Table 2

Pairwise Comparison Matrix

	C1	C2	C3	C4	C5
C1	(1, 1, 1)	(1.02, 1.26, 1.56)	(1.19, 1.49, 1.81)	(1.81, 2.29, 2.76)	(2.17, 2.75, 3.4)
C2	(0.64, 0.79, 0.98)	(1, 1, 1)	(1.07, 1.31, 1.59)	(1.62, 1.92, 2.22)	(1.64, 2, 2.39)
C3	(0.55, 0.67, 0.84)	(0.63, 0.76, 0.93)	(1, 1, 1)	(1.73, 2.17, 2.65)	(1.17, 1.48, 1.87)
C4	(0.36, 0.44, 0.55)	(0.45, 0.52, 0.62)	(0.38, 0.46, 0.58)	(1, 1, 1)	(1.08, 1.33, 1.67)
C5	(0.29, 0.36, 0.46)	(0.42, 0.5, 0.61)	(0.53, 0.67, 0.85)	(0.93, 0.75, 0.93)	(1, 1, 1)

After constructing the pairwise comparison matrix, the fuzzy extension of each row was calculated. Subsequently, defuzzification of the calculated values was performed, and there are various methods for defuzzification. In this study, the center of gravity method was used, and the results are presented in Table 3 and Figure 1. Based on this, the priority vector of the main criteria was obtained, and the results showed that causal factors, with a normalized weight of 0.302, had the highest priority. Contextual factors, with a normalized weight of 0.241, ranked second. Intervening factors, with a normalized weight of 0.210, ranked in the middle. The inconsistency rate was 0.014, which is less than 0.1, indicating that the comparisons made are reliable.

Table 3

Defuzzification of the Final Weights of the Main Criteria

Criterion	X1maxX1_{max}X1max	X2maxX2_{max}X2max	X3maxX3_{max}X3max	Defuzzified	Normalized
Causal Factors	0.313	0.311	0.309	0.313	0.302

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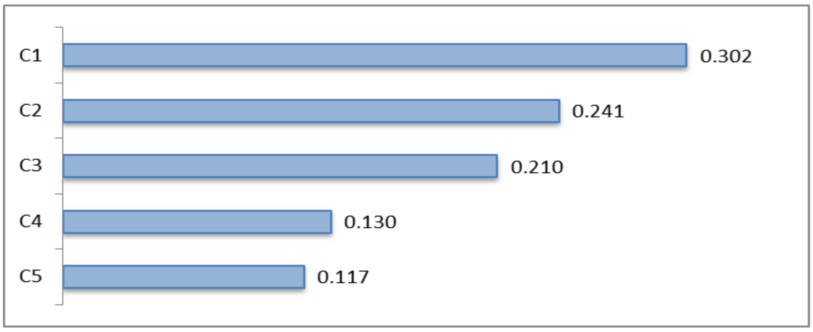
Contextual Factors	0.249	0.248	0.246	0.249	0.241
Intervening Factors	0.218	0.216	0.214	0.218	0.210
Strategies	0.135	0.133	0.132	0.135	0.130
Outcomes	0.121	0.119	0.117	0.121	0.117

Figure 1

Graphical Representation of the Main Criteria Based on the Objective



In the second step of the FAHP technique, the sub-criteria related to each category of the main criteria were pairwise compared. The pairwise comparisons of each cluster were examined separately.

The sub-criteria for causal factors include individual factors, organizational factors, and social factors. Based on the obtained priority vector, the S13 indicator, with a weight of 0.388, is more important than the other indicators. The inconsistency rate of the comparisons made is 0.020, which is within the tolerance threshold of 0.1.

The sub-criteria for contextual factors include organizational contexts and managerial contexts. Based on the obtained priority vector, the S21 indicator, with a weight of 0.385, is more important than the other indicators. The inconsistency rate of the comparisons made is 0.054, which is within the tolerance threshold of 0.1.

The sub-criteria for intervening factors include organizational factors and supra-organizational factors. Based on the obtained priority vector, the S32 indicator, with a weight of 0.385, is more important than the other indicators. The inconsistency rate of the comparisons made is 0.055, which is within the tolerance threshold of 0.1.

The sub-criteria for strategies include human resources strategies, managerial strategies, and social strategies. Based on the obtained priority vector, the S41 indicator, with a weight of 0.377, is more important than the other indicators. The inconsistency rate of the comparisons made is 0.045, which is within the tolerance threshold of 0.1.

The sub-criteria for outcomes include individual outcomes, organizational outcomes, and social outcomes. Based on the obtained priority vector, the S52 indicator, with a weight of 0.575, is more important than the other indicators. The inconsistency rate of the comparisons made is 0.025, which is within the tolerance threshold of 0.1.

In the following study, a fuzzy expert system is proposed to examine the impact of input variables on organizational performance and innovation. Among the factors, causal factors were found to be more important than contextual and intervening factors, and within the causal factors, social factors were identified as the most important. In the strategies, human resources were recognized as the most significant, and ultimately, organizational outcomes were considered the most important results. The ranking output is utilized to design the rules of the expert system. Since the number of indicators is very large, it is not logical to design a fuzzy expert system with all of these indicators. Therefore, indicators with higher ranks were selected for the fuzzy expert system design. In the design of the fuzzy expert system, social causal factors, human resources strategies, and organizational outcomes were considered, and rules were defined for them.

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Table 4

Social Causal Factors, Human Resources Strategies, and Organizational Outcomes

Factors	Components	Code	Number
Social Factors	Social Correlation	Social Relationship	S20
		Relationships with Citizens	S21
		Relationships with Employees	S22
Human Resources Strategies	Selection and Appointment	Management Recruitment and Selection System	S25
		Importance of Emotional and Social Intelligence in Selection	S26
		Job-Person Fit (Managers)	S27
		Meritocracy in Appointments	S28
		Educational Interventions	
		Micro-oriented Socialization	S29
		Training in Critical Thinking Skills	S30
		Self-Awareness and Value System Recognition	S31
		Development of Performance Capacities	S32
		Organizational Learning	
		Effective Organizational Communication	S33
		Succession Planning and Coaching Managers	S34
		Facilitating Collaborative Learning (Knowledge and Experience)	S35
		Predicting Appropriate Motivational Systems	S36
Organizational Outcomes	Improving Service Quality	Costs Resulting from Organizational Errors (Decision-Making)	S63
		Improving Organizational Decision-Making	S64
		Optimal Use of Resources (for Public Interest)	S65
		Trust in the Quality of Services Provided	S66
	Stakeholder Satisfaction	Service Recipient Satisfaction	S67
		Job Satisfaction of Managers and Employees	S68
	Organizational Dynamism and Agility	Speed in Response	S69
		Speed in Decision-Making	S70
		Flexibility in Action	S71
		Power to Face Challenges	S72
		Facilitating Work while Adhering to Regulations	S73
		Utilizing Collective Wisdom in Decision-Making (Dynamism)	S74
	Organizational Vitality	Interest and Commitment to the Profession	S75
		Appropriate Interaction with Colleagues and Managers	S76
		Participation in Matters and Decision-Making	S77
		Feeling Secure and Trusting the System	S78
		Creating Employee Satisfaction and Motivation	S79
	Organizational Citizenship Behaviors	Sense of Responsibility towards Stakeholders	S80
		Voluntary Help and Support	S81
		Skill and Ability Development	S82
		Acceptance and Endurance of Constraints	S83

According to Table 4, two types of inputs and one type of output are considered for the fuzzy expert system. One input type is related to social causal factors, and the other input type is related to human resources strategies. There is also one output type, which is related to organizational outcomes. Since there are five outputs in organizational outcomes, five fuzzy expert systems are designed. For designing the fuzzy expert system, the numerical value of each variable was fuzzified. This was done using membership functions. For fuzzifying the output variable, a triangular membership function was used, and for fuzzifying the input variables, a Gaussian membership function was used. For the membership functions of all variables, a range of 0 to 1 was considered.

Table 5

Input Variables

Verbal Variable	Gaussian Fuzzy Number
Low (L)	(0.15, 0)

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Medium (M)	(0.15, 0.5)
High (H)	(0.15, 1)

Table 6

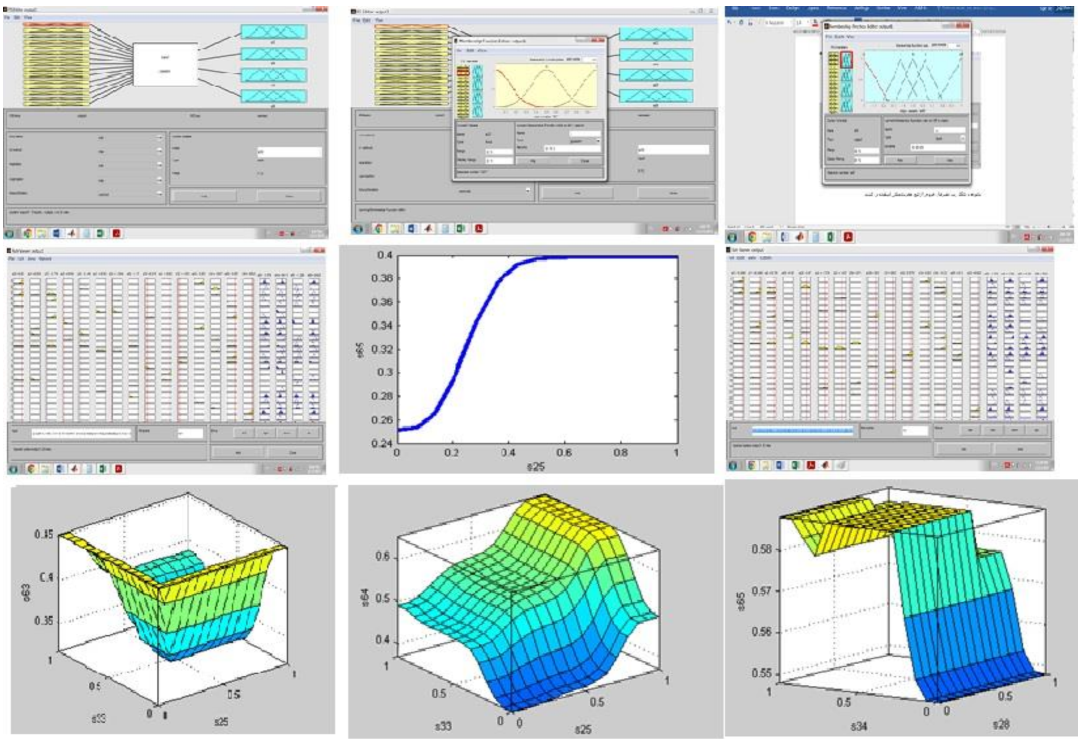
Output Variable

Verbal Variable	Triangular Fuzzy Number
Very Low (VL)	(0, 0, 0.25)
Low (L)	(0.2, 0.375, 0.55)
Medium (M)	(0.325, 0.5, 0.675)
High (H)	(0.45, 0.625, 0.8)
Very High (VH)	(0.75, 1, 1)

After converting the input and output variables to fuzzy numbers and defining the fuzzy rules, fuzzy inference is performed. Since there are five types of outputs, five fuzzy inference systems are used to determine organizational performance. MATLAB software was used to implement the fuzzy inference system. The fuzzy expert system model for the first output is shown in Figure 2. As shown, the output variables use the triangular membership function. The first fuzzy inference system used 25 rules, and the set of rules after inference is shown in the figure. Figure 7 shows that by improving the indicator of the management recruitment and selection system, the value of the optimal use of resources indicator increases and improves. If we observe the surface chart, we can examine the relationship between the input variables and the output. As shown in Figure 2, with an increase in the two variables S25 and S33, the value of the S63 variable significantly decreases. Also, Figure 2 shows that the value of the S64 variable increases with the increase in the S25 and S33 indicators.

Figure 2

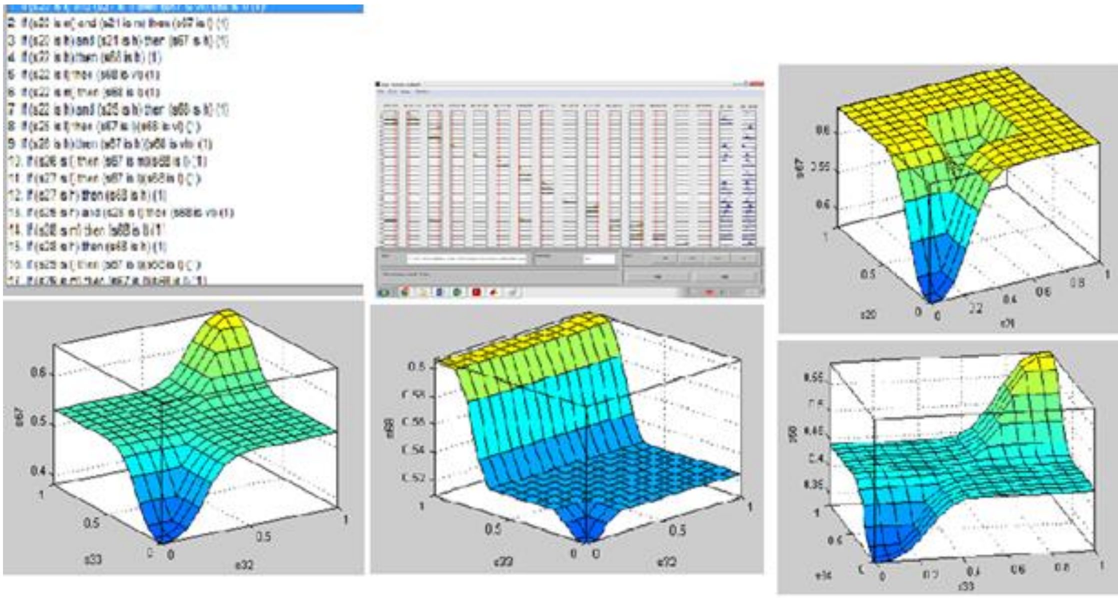
Fuzzy Expert System Model for the First Output



Next, the results of the second fuzzy inference system and the analysis of the rules related to stakeholder satisfaction are presented (Figure 3). This means how the input variables affect stakeholder satisfaction. The input variables in this system are the same as in the previous system. In this system, 33 rules were defined. For example, the first rule states that if the value of the S20 indicator is low and the value of the S21 indicator is also low, then the value of the S67 indicator is very low, and the S68 indicator is low.

Figure 3

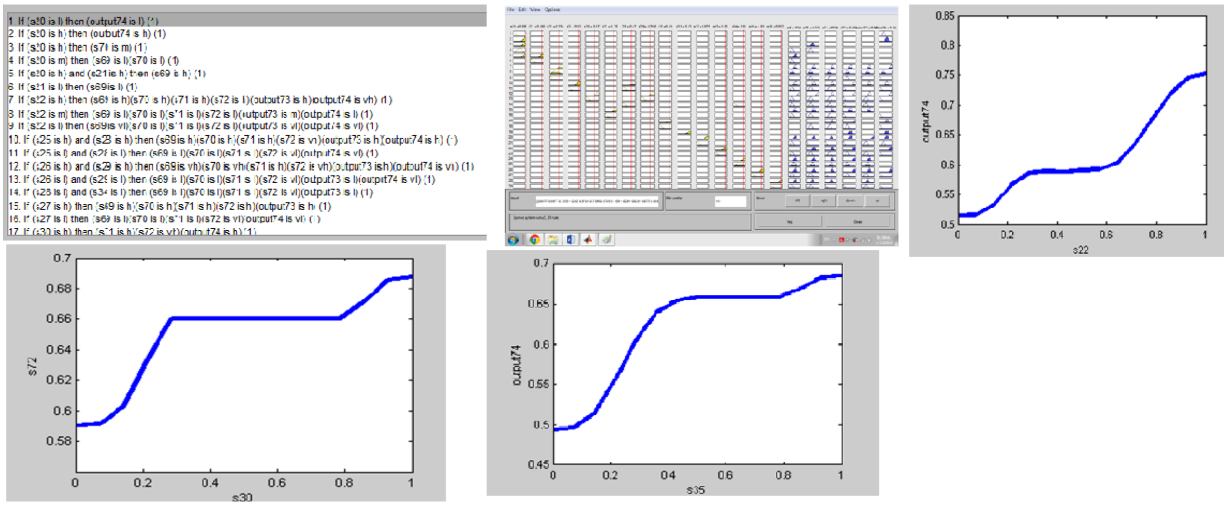
Fuzzy Expert System Model for the Second Output



Next, the third fuzzy expert system output is presented (Figure 4). This system has the same inputs as the first and second systems. The output of this system is organizational dynamism and agility. This main indicator has six sub-indicators: speed in response, speed in decision-making, flexibility in action, power to face challenges, facilitating work while adhering to regulations, and utilizing collective wisdom in decision-making. Then, fuzzy rules were designed for these six indicators, and 29 rules were identified. It can be concluded that developing performance capacities and effective organizational communication positively affect service recipient satisfaction. Additionally, the S33 and S34 variables significantly influence the S68 variable.

Figure 4

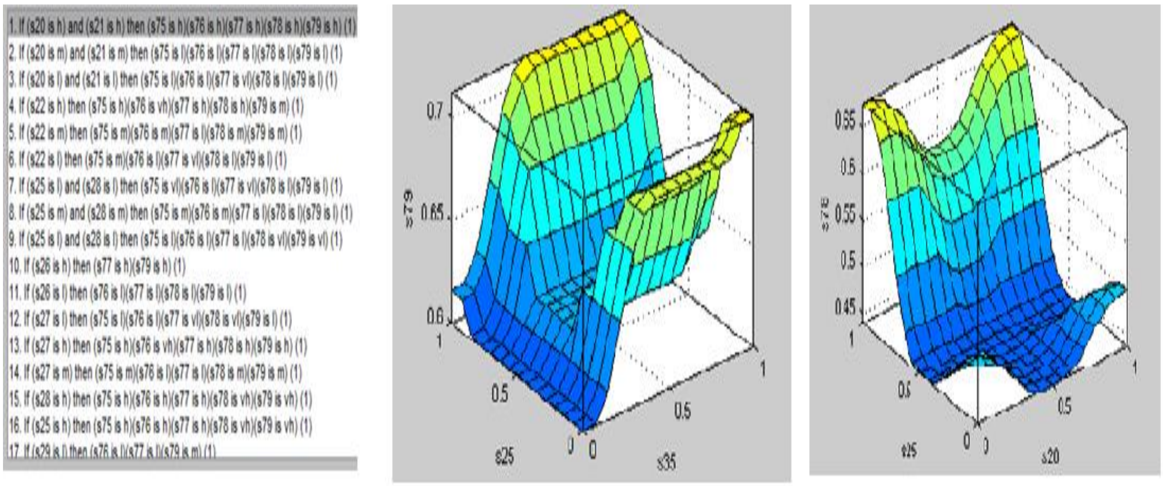
Fuzzy Expert System Model for the Third Output



Next, the results of the fourth fuzzy expert system are presented (Figure 5). This system has the same inputs as the previous systems, but the outputs differ. This system evaluates organizational vitality. The indicators include interest and commitment to the profession, appropriate interaction with colleagues and managers, participation in matters and decision-making, feeling secure and trusting the system, and creating employee satisfaction and motivation. Figure 5 shows the rules created in the fourth system and the surface plot. This system has 33 rules.

Figure 5

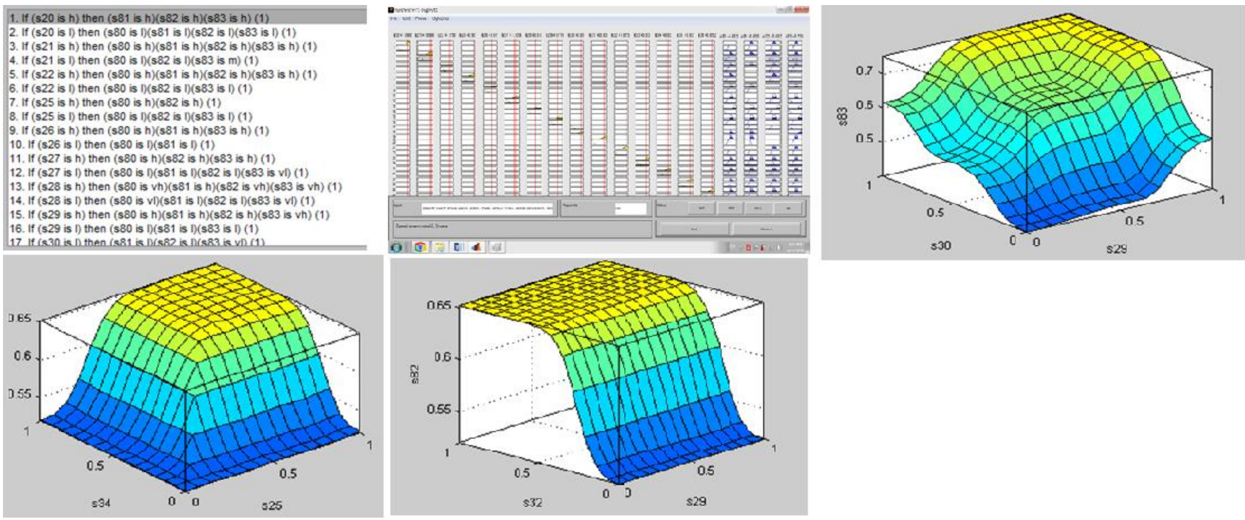
Fuzzy Expert System Model for the Fourth Output



Finally, the fifth fuzzy expert system is presented. The inputs are the same as in the previous systems, but the output is the organizational citizenship behavior indicator, which has four sub-indicators: a sense of responsibility towards stakeholders, voluntary help and support, skill and ability development, and acceptance and endurance of constraints. For example, Rule 25 shows that if the S34 indicator is high, then the values of the S80 to S83 indicators are high. This means that if succession planning and coaching managers are high (in a good state), the sense of responsibility towards stakeholders, voluntary help and support, skill and ability development, and acceptance and endurance of constraints increase. For example, in Figure 6, it is observed that with an increase in the S29 and S30 indicators, the value of the S83 indicator increases. In other words, if the micro-oriented socialization and training in critical thinking skills indicators increase, the acceptance and endurance of constraints improve.

Figure 6

Fuzzy Expert System Model for the Fifth Output



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4 Discussion and Conclusion

In this study, the research indicators were initially identified using grounded theory. Causal conditions, strategies, outcomes, contextual factors, and intervening variables were specified, and through fuzzy Delphi screening, the final indicators were determined, followed by the extraction of the final model for the qualitative section of the research. As a result, among the factors, causal factors were found to be more important than contextual and intervening factors, with social factors being the most significant among the causal factors. In the strategies category, human resources were identified as the most important, and ultimately, organizational outcomes were considered the most significant results. Knowledge management directly impacts organizational performance and innovation. By collecting and sharing knowledge, employees gain access to important information and experiences, enabling tasks to be completed more quickly and effectively. This process helps managers make better decisions by having more accurate and comprehensive knowledge. Additionally, by leveraging successful past experiences, similar problems within the organization are solved more efficiently and with better solutions. Knowledge management also facilitates innovation (Noruzy et al., 2013). By disseminating ideas and knowledge across the organization, a space is created for creativity and the development of new ideas. Organizations can achieve continuous innovation by learning from past experiences and applying new knowledge. Knowledge management also enhances communication and collaboration between departments and individuals, fostering collaborative innovations and synergies. In this way, knowledge management contributes to improving performance and increasing innovation within the organization, helping it achieve its goals (Rehman & Iqbal, 2020).

Intellectual capital includes intangible assets such as knowledge, skills, experiences, and organizational relationships, which play a significant role in organizational performance and innovation. The knowledge and skills of employees, a primary aspect of intellectual capital, help the organization increase its productivity. Employees with high levels of knowledge and expertise can improve the organization's performance by enhancing work processes and providing new solutions (Kiessling et al., 2009). The internal systems and processes of the organization are another component of intellectual capital. These systems help the organization effectively manage existing knowledge and experiences and use them to optimize performance. Organizations with efficient systems for collecting and applying knowledge can leverage this advantage to reduce costs and increase efficiency (Lee et al., 2012). Organizational relationships with customers and partners, as part of intellectual capital, enable the organization to create new products and services by better understanding market needs. Customer feedback can contribute to continuous innovation and improvement, allowing the organization to respond more quickly to market changes and needs (Iqbal et al., 2021). Moreover, organizational culture plays a key role in encouraging innovation. Organizations with an innovation-oriented culture provide an environment where employees are encouraged to present new ideas. This culture drives organizations to continually innovate and introduce new products and services (Albassami et al., 2019). Overall, intellectual capital helps the organization enhance its performance and lead in innovation by optimizing the use of its intangible resources. Focusing on intellectual capital and managing it effectively can help the organization create a sustainable competitive advantage, leading to greater success in the market (Noruzy et al., 2013).

In summary, it can be stated that evaluating organizational performance and innovation based on the role of knowledge management and intellectual capital is of great importance. Utilizing a fuzzy expert system approach in this context can significantly assist managers and decision-makers in assessing organizational performance and innovation.

Authors' Contributions

All authors have contributed significantly to the research process and the development of the manuscript.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

Acknowledgments

IJIMOB E-ISSN: 3041-8992

We would like to express our gratitude to all individuals helped us to do the project.

Declaration of Interest

The authors report no conflict of interest.

Funding

According to the authors, this article has no financial support.

Ethical Considerations

In this research, ethical standards including obtaining informed consent, ensuring privacy and confidentiality were observed.

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IJIMOB
E-ISSN: 3041-8992