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Evaluation Commercialization Challenges and Resolutions in SMEs Using ML-FCM (Case study: Sanat Prozheh Toos)

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ABSTRACT

Commercialization of innovative products in small and medium-sized enterprises (SMEs) faces many challenges. In this study, the factors related to the existing challenges and resolutions are identified with the help of the multi-layer fuzzy cognitive mapping (ML-FCM) method. The most effective criterion is introduced by examining the centrality. Also, the challenges and the existing resolutions to overcome these challenges are specified, and the most effective ones are determined. The present study addresses the practical experience of Sanat Prozheh Toos Company, which operates in the design and production of mechanical noise pollution control equipment (e.g., Silencers). The data is collected based on the organization's documents and experts' opinions. Research findings confirm that among the challenges of commercialization of innovative products associated with the case study, management challenge has the highest degree of effectiveness and centrality; moreover, among the ways of overcoming these challenges, organizational integration has the highest degree of centrality. Thus, the findings provide policy and management suggestions for SMEs policymakers and managers in commercializing advanced technologies.

Keywords

Small and medium-sized enterprises (SMEs), Silencer, Noise pollution, Commercialization, Multi-layer fuzzy cognitive mapping method (ML-FCM).

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1. Introduction

Due to the rapid growth of technologies and the reduction of the product life cycle, the commercialization problems of advanced and innovative products have been highlighted. Most companies have expanded their activities in this field (Khalil Zadeh et al., 2017). Commercialization is the process by which knowledge and technology are transferred from universities and research centres to new industries and businesses. This complex process is influenced by many infrastructural, technological, social, political, and historical factors. New and innovative commercializing technologies face many obstacles in this field due to financial reasons and the lack of understanding of optimal organizational strategies (Dehghani, 2015). Despite considerable investments in this field, the rate of commercialization of technologies is reported to be lower than expected (Khalil Zadeh et al., 2017). Examining the commercialization process of various innovations shows that in the initial stages of commercialization development, the organization faces challenges that result in the highest rate of failure and stoppage. Organizations that pass this stage can obtain the produced value and create wealth.

In this research, we seek to identify and determine the most practical challenges of passing through the stage of the growth process called the valley of death and identify the solutions and capabilities of the organization to give this stage. The valley of death is considered a factor in the survival of companies and organizations when a technology-oriented and innovative business is trying to commercialize and earn money commercially. Barriers due to financial conditions, changing market needs, and focusing on technical and ignoring the management aspects of the business are created (Frank et al., 1996; Hudson and Khazragui, 2013; Ellwood et al., 2022; Rajabi et al., 2022). Therefore, in response to many structural, managerial, financial, and marketing challenges, policymakers and researchers in technology commercialization have provided resolutions to get out of these crises. Since the logic of science is different from commercialization, the transition from the stage of scientific research to the commercialization of technology must be managed to avoid obstacles. Researchers have provided various ways to help overcome these challenges.

This paper uses the multi-layered fuzzy cognitive mapping (ML-FCM) method to determine and identify the most critical factors in commercializing innovative products and resolutions to overcome these challenges of small and medium-sized enterprises (SMEs). The ML-FCM technique is one multi-criteria decision-making (MCDM) method that extended from the FCM

technique (Roozkhosh and Kazemi, 2022). these methods help the decision-maker to assess all these criteria (Modares et al., 2022; Bafandegan Emroozi and Fakoor, 2023; Modares et al., 2023). Since a lot of criteria are involved in supplier selection, it is an MCDM technique. MCDM methods are used when the aim chooses the critical criteria among many options based on the desired outcome (Modares et al., 2021; Modares et al., 2023). MCDM methods are a reliable approach for obtaining the appropriate solution. Using MCDM techniques, criteria are comprehensively surveyed from the perspective of multiple, conflicting, and interactive factors, and those that do not provide the minimum level of utility are removed from the process due to low importance in prioritization (Bafandegan Emroozi et al., 2022; Modares et al., 2023). When there are many criteria in making a decision and the decision-makers are confused about the options that must meet the criteria, one of the best ways is to compare the options and choose the best one and make a decision in the choice (Farimani et al., 2022; Modares et al., 2023; Roozkhosh et al., 2022).

The case study in this paper is Sanat Prozheh Toos Company, which designs and manufactures mechanical pollution and noise control equipment. Since the company is small and the vision and mission are based on innovation and have high research, and development activities, it has been chosen as the case study in this research. The rest of the paper is organized as follows. Section 2 describes the literature review of the subject. Section 3 discusses the research process. The findings are presented in Section 4. The conclusion is given in Section 5.

2. Literature review

2.1. The valley of death in technology commercialization

For the first time, the meaning and concept of Death Valley were proposed by Bruce Merrifield. This definition first referred to the challenges in transferring technologies in the agricultural industry. In the subsequent years, this concept was used to describe the gap between scientific research and the commercialization of products in organizations (Markham et al., 2010). The valley of death represents the gap between the research stage and developing a new product. Technology start-up companies go through such challenges in the innovation process, from the idea generation stage to the commercialization of the product**.**

(Klitsie et al., 2019; Dean et al., 2022). Despite having a product or service prototype, a vast number of companies may fail to commercialize the product (Hudson and Khazragui, 2013). The results of previous research indicate that the significant commercialization problems in

technology start-up companies can usually be categorized into four main areas. These four main areas are shown in Figure 1 (Pellikka and Virtanen, 2009).

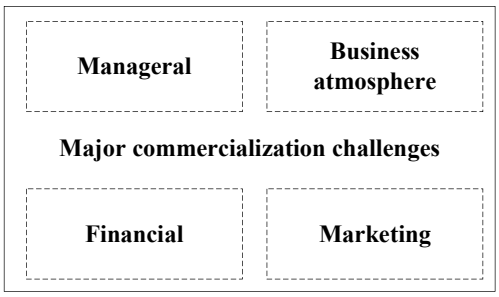

Figure 1. Commercialization problems

2.2. Multi-Layer fuzzy cognitive methods (ML-FCM)

ML-FCMs can be argued as an extended form of FCMs by using sub-FCMs. Sub-FCMs are smaller FCMs organized into layers that extend and decompose some concepts in the immediately higher layer (Fig. 1) (Christoforou and Andreou, 2017). This makes it possible to get a more detailed model and account for different levels of performance and decision-making in a single framework.

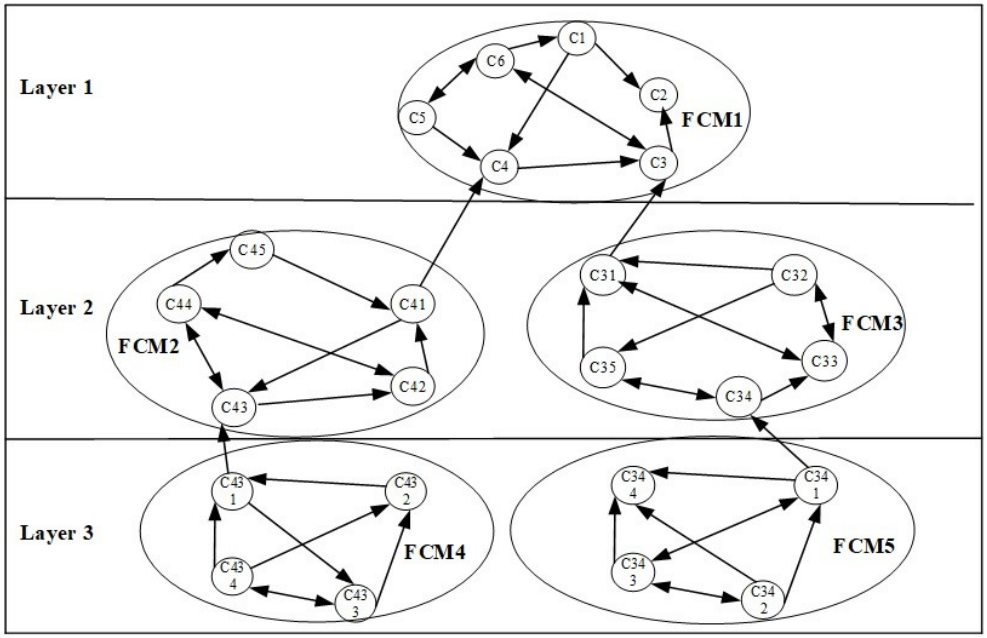

Figure 2. Example of a ML-FCM representation with three layers

ML-FCMs have been used to model complex systems in several scientific fields in recent years, as they allow the analysis of system parameters at higher specificity levels (Roozkhosh and Motahari). A ML-FCM framework was developed and applied to represent and simulate the cloud adoption decision problem (Christoforou and Andreou, 2017).

3. Research process

The research steps are shown in Figure 3.

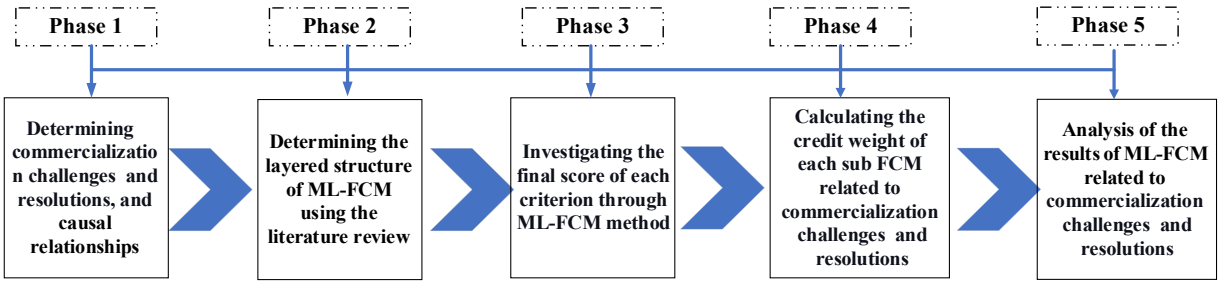

Figure 3. Research steps

3.1. Step 1: Determining commercialization challenges and resolutions, and causal relationships

At this stage, the challenges that exist on the way to the commercialization of innovative products are identified, and the causal relationships between these commercialization-inhibiting factors are collected based on the opinion of experts. Solutions to get out of these challenges are also collected based on previous research and experts' opinions, and causal relationships between the factors to get out of the challenges are also determined.

3.1.1. *Constructing the matrix of pairwise comparisons and weights vector at each level*

In this step, the relative weight of each component and sub-components is obtained through experts and the group pairwise comparisons matrix. ML-FCM graphs provide either the interviewee or modeler having the ability to give additional insights, concepts, and beliefs about a specific domain. Furthermore, the interdependencies and interrelations of criteria are also specified (Dickerson and Kosko, 1994; Palmer and Bolderston, 2006; Christoforou et al., 2017; Iraji, 2019).

3.2. Step 2. Determining the layered structure of ML-FCM using the literature review

Tables 1 and 2 show the FCMs of each layer and their respective concepts associated with challenges and resolutions, respectively. The concepts were selected based on a literature review on challenges and their solutions in connection with commercialization innovation products. For example, FCM 1 concepts represent total challenges. FCM 2 concepts represent management, FCM 3 concepts represent the business atmosphere and legal requirements, FCM 4 concepts illustrate finance, FCM 5 concepts show marketing, and FCM 6 concepts represent

human resources. Evaluation criteria are obtained by reviewing the literature, knowledge, experience of experts, and other appropriate methods.

Table 1.Layers, FCMS and concepts for commercialization challenges

	Layer	FCM	ID	Concepts	References
Challenges	Layer 1	FCM 1_c (Main FCM)	C1	Managerial	
			C2	The business atmosphere and legal requirements	
			C3	Financial	
			C4	Marketing	
			C5	Human resource	
	Layer 2	FCM 2_c (Sub FCM)	C1	Managerial	
			C11	Uncoordinated planning	(Nevens, 1990; Abetti, 2004)
			C12	Lack of effective use of all facilities	(Sharma, 2005)
			C13	Lack of proper organization	(Nevens, 1990; Abetti and Rancourt, 2006)
			C14	Failure to use opportunities in the marketing	(Nevens, 1990; Kelley and Rice, 2002; Waters and Smith, 2002; Sharma, 2005)
			C15	Inability to identify strategic factors	
		FCM 3_c (Sub FCM)	C2	The business atmosphere and legal requirements	
			C21	Existence of specific legal requirements	(Kelley and Rice, 2002; Waters and Smith, 2002; Chen et al., 2011)
			C22	Lack of environmental monitoring	(Heydebrecket al., 2000)
			C23	Insufficient knowledge of the environment	(Abetti and Rancourt, 2006; Madrid-Guijarroet al.,, 2009)
		FCM 4_c (Sub FCM)	C3	Financial	
			C31	Lack of proper policies and facilities	(Heydebrecket al., 2000; Waters and Smith, 2002)
			C32	Allocation of excessive financial resources to (R&D)	(Kelley and Rice, 2002)
			C33	lack of investment for commercialization	(Madrid-Guijarroet al.,, 2009)
			C34	Limited access to financial resources	(White and Bruton, 2011)
		FCM 5_c (Sub FCM)	C4	Marketing	
			C41	Lack of continuity in the environmental scanning	(Daymon and Holloway, 2011)
			C42	A one-sided focus on the technical aspects of product development	(Heydebrecket al., 2000; Sharma, 2005)
			C43	Failure to understand the market potential of the product	(Sharma, 2005)
			C44	Starting marketing activities at the wrong time	(Hudson and Khazragui, 2013)
			C45	Ignoring the financial benefits of other people outside the organization is effective in marketing	(Khalil Zadeh *et al.*, 2017)
			C46	Receiving inaccurate information from competitors	(Pellikka and Virtanen, 2009)
		FCM 6_c (Sub FCM)	C5	Human resource	
			C51	Inexperience workforce	(Khalil Zadeh *et al.*, 2017)
			C52	Lack of identification of opportunities in the market	(Arvanitis et al., 2008)
			C53	Unskilled workforce	(Stander and Broadhurst, 2021)

Table 2. Layers, FCMS and concepts for commercialization resolutions

	Layer	FCM	ID	Concepts	References
Resolutions	Layer 1	$FCM1_r$ (Main FCM)	C1	Innovation	
			C2	Organization integrity	
			C3	Adjustment	
	Layer 2	$FCM\ 2_r$ (Sub FCM)	C1	Innovation	
			C11	Adequate and appropriate allocation of resources to innovative activities	(Cooper, 2011; Dattaet al., 2013; Datta et al., 2015)
			C12	Providing new and creative ideas	((Cooper, 2011)
			C13	Providing innovations fits the target market	(Khalil Zadeh *et al.*, 2017)
			C14	Making improvements on past products to suit the target market	(Datta et al., 2015; Khalil Zadeh *et al.*, 2017)
			C15	Ability to identify environmental opportunities	(Chiesa and Frattini, 2011)
			C16	Creating a balance between risks and benefits	(Arvanitis et al., 2008)
		$FCM\ 3_r$ (Sub FCM)	C2	Organization integrity	
			C21	Common work procedures	(Kotha et al., 2013)
			C22	Integrated problem-solving in all units of the organization	(Madrid-Guijarro et al.,, 2009; Khalil Zadeh *et al.*, 2017)
			C23	Common vision and consensus regarding the mission of the organization	(Lichtenthaler, 2005; Cooper, 2011; Stander and Broadhurst, 2021)
		$FCM\ 4_r$ (Sub FCM)	C3	Adjustment	
			C31	Adaptability to the market	(Stenroos and Lehtimäki, 2013)
			C32	Identifying new opportunities to offer innovative products	(Khalil Zadeh *et al.*, 2017)
			C33	Adjustment to new policies	(Jung et al.,2015; (Khalil Zadeh *et al.*, 2017)

3.3. Step 3. Investigating the final score of each criterion through the ML-FCM method

3.3.1. Constructing the adjacency matrix

A comparison scale has been chosen to compare the relative importance of the components. This step requires setting criteria for decision-making (Hejazi and Roozkhosh, 2019). The fuzzy comparison scale is included the levels presented in Table 3.

Table 3. Comparison scale levels

Fuzzy number	Linguistic variables
(0.8,0.9,1)	Positive very big (PVB)
(0.6,0.75,0.9)	Positive big (PB)
(0.3,0.5,0.7)	positive medium (PM)
(0.1,0.25,0.4)	positive small (PS)
(0,0.1,0.2)	Positive very small (PVS)
(-0.1, -0.2,0)	Negative very small (NVS)
(-0.4, -0.25, -0.1)	Negative small (NS)
(-0.7, -0.5, -0.3)	Negative medium (NM)
(-0.9, -0.75, -0.6)	Negative big (NB)
(-1, -0.9, -0.8)	Negative very big (NVB)

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3.3.2. Adjacency matrix

The values of the criteria are determined concerning each other, which are quantified by the table of fuzzy numbers and are diffused by equation 1:

$$R_{ij}^{*k} = \frac{u + 4m + l}{6} \quad (1)$$

After drawing the cognitive mapping and coding the adjacent matrix, the model is executed to see where the system will converge. If this happens, they reach steady values, and their state will not change. These calculations are obtained using an automated neural network.

$$A_i^t = f(\sum_{\substack{j=1 \\ j \neq i}}^{N} A_j^{t-1} w_{ij} + A_j^{t-1}) \quad (2)$$

In equation 2, N is the total number of variables, A_j^{t-1} which is the value c_j at the time $t-$. w_{ij} is the effect of c_i on c_j . (c_i and c_j are the factors.). F(.) is a transfer function, which gives values of concepts in the range [0 1] and is formulated as follows:

$$f(x) = \frac{1}{1 + e^{-mx}} \quad (3)$$

Where m is a positive real number, and x is the value $A_i^{(k)}$ at the equilibrium point. As shown in equation 3, a sigmoid function is a threshold function that converts the result to a number in the interval [0,1]. Network convergence makes it possible to predict the future stable state of the system and make the right decisions. The inference and simulation process uses a bottom-up approach from layer 2 to layer 1. First, the inference process is performed independently in the sub-graphs of layer 2. Then the inference process is performed in layer 1, using the equilibrium point results from layer 1 as the input activation levels of the transmission concepts.

3.4. Step 4. Calculating the credit weight of each sub-FCM related to commercialization challenges and resolutions

The matrix obtained from the third stage is considered the input of fuzzy cognitive mapping and UCINET software. The criteria' degree of input, output, and centrality are specified. The absolute value of the inputs to each criterion indicates the effect value. Also, the absolute value of the output of each criterion is the influence value. The sum of the input and output degrees of each criterion indicates the centrality of that criterion. The effect value (input flow), influence (output flow), and degree of centrality for challenge and resolution criteria are calculated using

the adjacency matrix in each node in Tables 3 and 4, respectively. Finally, a cognitive map of the main performance appraisal criteria is drawn. Edges indicate the direction and extent of the impact of one criterion on another. Figures 4 and 5 illustrate the ML-FCM model (i.e., main FCM) for commercialization challenges and resolutions for innovation products using data and following the steps described in the previous section, respectively.

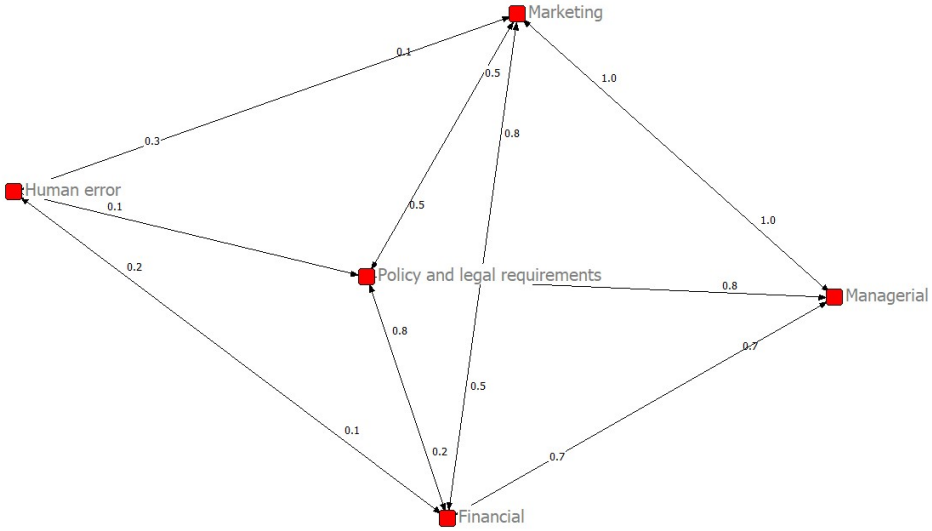

Figure 4. Investigating the impact of criteria associated with challenges FCM 1_c

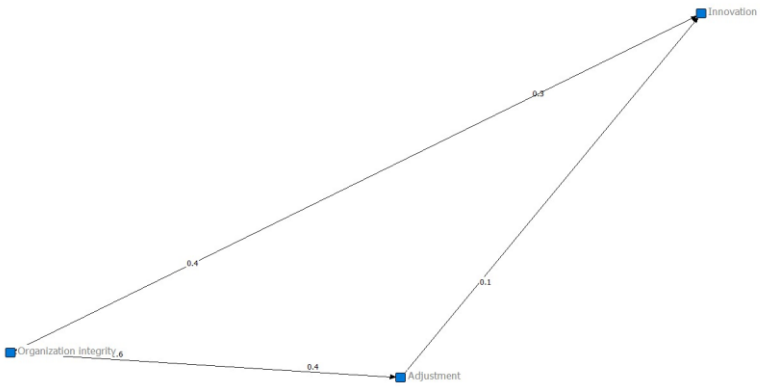

Figure 5. Investigating the impact of criteria associated with resolutions FCM 1_r

Moreover, the criteria relationships and effect relations between nodes in each sub-FCM are calculated. Each node represents a variable in these figures, and the input and output values are marked with numbers on the vectors. Figure 6 shows the ML-FCM model (i.e., sub-FCM of C4) for commercialization challenges associated with marketing factor through data and following the steps described in the previous section. It is calculated in the same way for other sub-layers, including managerial, the business atmosphere and legal requirements, financial and human resources.

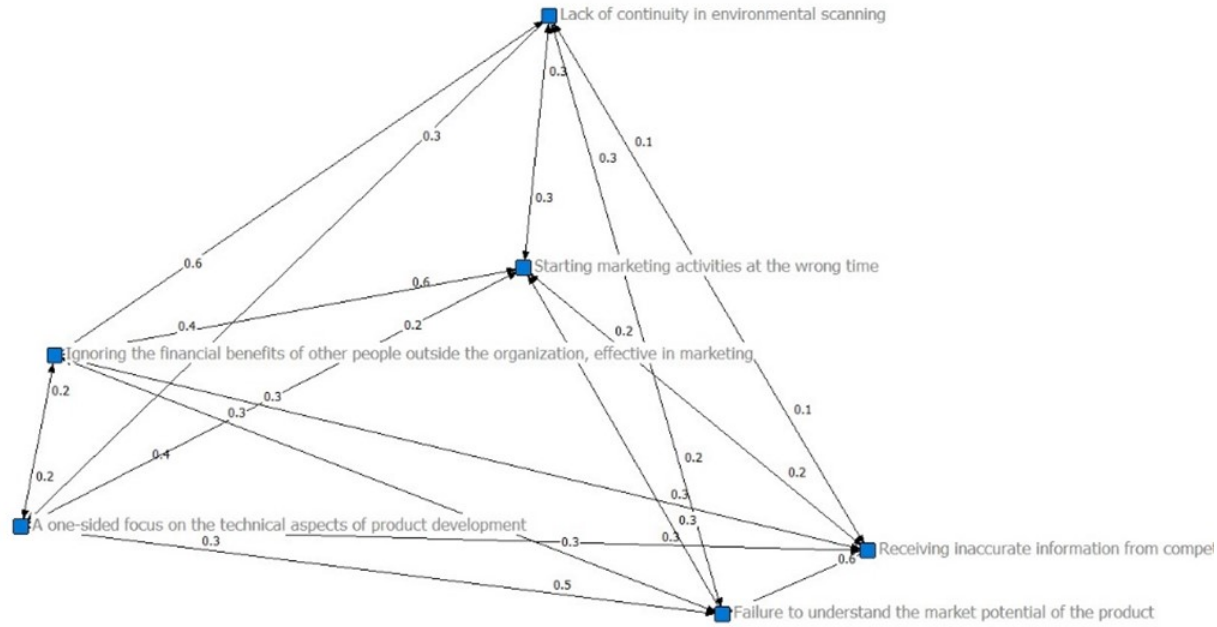

Figure 6 - Investigating the impact of sub-criteria associated with challenges sub FCM of C4 (i.e., Marketing)

Figure 7 shows the ML-FCM model (i.e., sub-FCM of C1) for commercialization resolutions related to innovation factor through data and following the steps described in the previous section. Other sub-layers, including organization integrity and adaptation likewise are calculated.

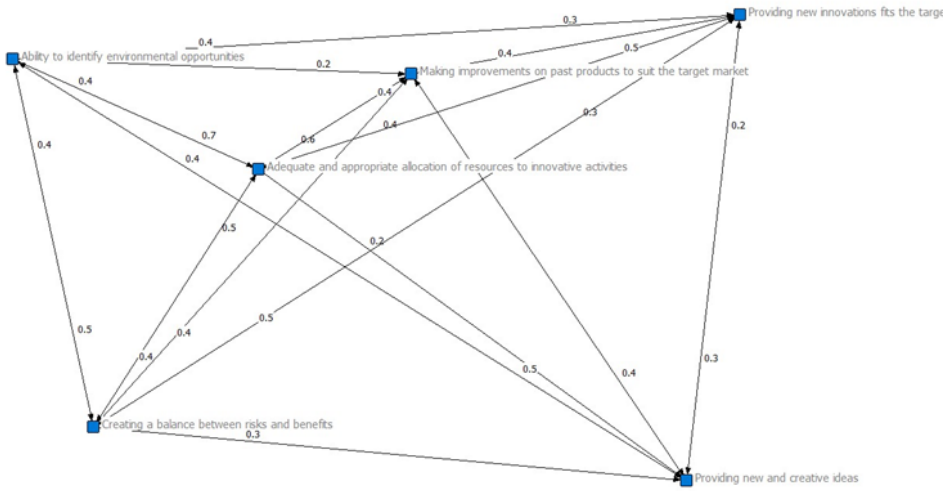

Figure 7- Investigating the impact of sub-criteria associated with challenges sub FCM of C1 (i.e., Innovation)

3.5. Step 5. Analysis of the results of ML-FCM related to commercialization challenges and resolutions

The main results of this paper are the framework of the ML-FCM model for challenge and resolution factors and the convergence values of the concepts in each FCM after running the simulations. Figures 4 and 5 illustrate the ML-FCM model through data and follow the steps

described in the previous section. The model construction is analyzed by calculating the sum of the weights of incoming (effect value) and outgoing (influence) edges to node i and total value (centrality), and are calculated as follows:

$$Value_{in}(i) = \sum_{j} \omega_{ji} \tag{4}$$

$$Value_{out}(i) = \sum_{j} \omega_{ij} \tag{5}$$

$$Total\ Value(i) = Value_{in}(i) + Value_{out}(i)$$

Centrality for the challenge and resolution criterion are shown in Tables 3 and 4, respectively. Based on the results of Table 3, each FCM of the model has density values above the medium complexity threshold, so it can be concluded that the ML-FCM model for the commercialization of innovative products in this work is a highly complex structure.

Table 4. Criteria value of each FCM and sub-FCM

	Layer	FCM	ID	Concepts	Value (in)	Value (out)	Total value (Centrality)
Challenges	Layer 1	FCM1 (Main FCM)	C1	Managerial	2.5	2.4	4.9
			C2	The business atmosphere and legal requirements	2.1	1.5	3.6
			C3	Financial	1.5	2.5	4
			C4	Marketing	2.4	2.3	4.7
			C5	Human resource	0.5	0.3	0.8
	Layer 2	FCM2 (Sub FCM of C1)	C11	Uncoordinated planning	2.3	2.4	4.7
			C12	Lack of effective use of all facilities	2.2	0.9	3.1
			C13	Lack of proper organization	2.2	1.6	3.8
			C14	Failure to use opportunities in the marketing	1.9	2.1	4
			C15	Inability to identify strategic factors	0.4	0.3	0.7
		FCM3 (Sub FCM of C2)	C21	Existence of specific legal requirements	0.4	0.3	0.7
			C22	Lack of environmental monitoring	0.7	0.3	1
			C23	Insufficient knowledge of the environment	0.4	0.1	0.5
		FCM4 (Sub FCM of C3)	C31	Lack of proper policies and facilities	0.9	0.6	1.5
			C32	Allocation of excessive financial resources to (R&D)	0.6	0.9	1.5
			C33	lack of investment for commercialization	0.4	0.6	1
			C34	Limited access to financial resources	0.9	0.7	1.6
		FCM5 (Sub FCM of C4)	C41	Lack of continuity in the environmental scanning	1	0.7	1.7
			C42	A one-sided focus on the technical aspects of product development	1.5	1.2	2.7
			C43	Lack of understanding of the market potential of the product	1.1	1.8	2.9
			C44	Starting marketing activities at the wrong time	1.6	1.3	2.9
			C45	Ignoring the financial benefits of other people outside the organization	1.2	1.4	2.6
			C46	Receiving inaccurate information from competitors	1.2	0.9	2.1
		FCM6 (Sub FCM of C5)	C52	Inexperience workforce	1.2	1.2	2.4
			C53	Unskilled workforce	1	1.3	2.3
				Lack of identification of opportunities in the market	1.1	0.9	2

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The highlighted rows in Tables 3 and 4 identify concepts of most importance in each FCM. These factors have the most significant impact on the commercializing of innovative products. The two most important concepts of the main FCM are managerial and marketing challenges. Furthermore, the two most important concepts of the main FCM are organization integrity and adaption resolutions.

Table 5. Criteria value of each FCM and sub-FCM

	Layer	FCM	ID	Concepts	Value (in)	Value (out)	Total value (Centrality)
Resolutions	Layer 1	$FCM1_r$ (Main FCM)	C1	Innovation	0.4	0.4	0.8
			C2	Organization integrity	1	0.7	1.7
			C3	Adaptation	0.4	0.7	1.1
	Layer 2	$FCM\ 2_r$ (Sub FCM of C1)	C11	Adequate and appropriate allocation of resources to innovative activities	2.4	2.2	4.6
			C12	Providing new and creative ideas	1.5	1.2	2.7
			C13	Providing innovations fits the target market	1.7	2	3.7
			C14	Making improvements on past products to suit the target market	1.4	1.4	2.8
			C15	Ability to identify environmental opportunities	1.2	2.1	3.3
			C16	Creating a balance between risks and benefits	1.4	1.9	3.3
		$FCM\ 3_r$ (Sub FCM of C2)	C21	Common work procedures	0.6	0.8	1.4
			C22	Integrated problem-solving in all units of the organization	0.5	0.6	1.1
			C23	Common vision and consensus regarding the mission of the organization	0.7	0.4	1.1
		$FCM\ 4_r$ (Sub FCM of C3)	C31	Adaptability to the market	0.5	0.3	0.8
			C32	Identifying new opportunities to offer innovative products	0.2	0.3	0.5
			C33	Adjustment to new policies	0.3	0.4	0.7

4. Finding

Table 4 shows the degree of effectiveness and the degree of centrality of the criteria for the commercialization of innovative products. Among the main FCM variables, management and marketing criteria play the most effect and centrality as the main factors of challenges in commercializing products in SMEs. In the second layer, all sub-FCM are considered, and the criteria with the highest degree of centrality are highlighted in each. Therefore, based on the obtained results, it can be concluded that the main challenges in the commercialization of innovative products are related to the study of management and marketing challenges. Uncoordinated planning, lack of understanding of the product's market potential, and starting marketing activities at the wrong time are considered the main sub-criteria in these challenges. Table 5 shows the degree of effectiveness and the degree of centrality of the criteria for the

commercialization of innovative products. Among the main FCM variables, the criteria of adaption and organization integrity play the most significant effect and centrality as the leading solutions to overcome the challenges of product commercialization in SMEs.

5. Conclusion

Given the development of innovations and the process of commercial enterprises, the development of innovations within each company's ecosystem is different and should be examined separately. Therefore, considering the case study, the innovation ecosystem of noise pollution control products and services has faced many challenges across the valley of death. Owing to the increasing complexity and dynamics of the environment, analyzing and managing innovation development cannot be limited to the environment within the company. Therefore, the boundaries beyond and broader than the company should be considered, which includes the more diverse challenge. ML-FCM is a powerful soft-computing tool for modeling complex systems that allow for the extension and decomposition of concepts by applying a multi-layered grouping approach. For the significant purpose of this research, we examined a period in the innovation ecosystem development process, which is equivalent to passing from a knowledge ecosystem to a business ecosystem (valley of death). Based on the results obtained, the challenges in this research include five categories of management, policy, legal, financial, marketing, and personnel requirements.

Creating a series of capabilities brings about the potential to perform activities in the ecosystem and overcome these challenges. Based on this, three strategies of innovation, including integration, adaptability, and effective implementation, were introduced as strategies to overcome these challenges. Creating a series of capabilities brings about the potential to perform activities in the ecosystem and overcome these challenges. Based on this, three strategies of innovation, including organization integration, innovation, and adaption, were introduced as strategies to overcome these challenges. Analyzing the density and strength indicators in the model construction made it possible to validate the high network complexity and the importance of the concepts used to commercialize innovative products. Furthermore, the convergence of the concept vectors in the inference process confirmed the initial selection of the concepts in the main FCM and the sub-FCMs. This work can help managers better understand factors affecting commercialization innovation products and the quantitative relationships between decision variables and comprehensive performance. Future work will

focus on considering a larger number of concepts and other transfer functions and learning algorithms.

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