Journal of System Management (JSM)
Online ISSN: 2538-1571, Print ISSN: 2322-2301
10(2), 2024, pp. 63-78

Received: 29/09/2023
Accepted: 17/12/2023

RESEARCH ARTICLE **Open Access**

Value Chains Analysis: Application of Fuzzy Cognitive Map in Pharmaceutical Industry

Meysam Kharaghani[1], Mahdi Homayounfar[2]*, Mohammad Taleghani[3]

Abstract

This study aims to investigate the factors influencing value chain (VC) in pharmaceutical industry, as a very important sector in Iran. The research method is descriptive-analytical in term of method. The required data have been collected from the experts of a public joint stock company. Conducting the research, first the literature of VC is reviewed to identify the initial factors affecting on VC of pharmaceutical companies. In this Phase, 34 factors were identified in 8 categories including; institutional, industry, political, economic, social, technological, legal and environmental factors. In the next step, a primal evaluation of the initial factors by 14 experts of the research, resulted to the 20 more important factors which were used in the modelling process. Due to the need for fuzzy logic regarding subjective judgments in cause-effect relationships between factors, the fuzzy cognitive mapping (FCM) method in FCM expert software is used to visualize the relationships among these factors. The results show that technological capabilities, government policies, company resilience, financial strength, medicine price, sustainable waste management, cost of raw materials, production technology, cost of energy, R&D, operational efficiency, recycling capabilities, transportation cost, VC governance (coordination/ partnerships/ integration), consumer behavior and social (market) trends, environmental concerns about waste disposal internet of things (IoT) and connected devices, non-value-adding activities, import limitations and skilled human resources, respectively are the most influencing factors on pharmaceutical VC.

Keywords: *Value Chain, Pharmaceutical Industry, Medicine, FCM, IoT*

Introduction

Value chain (VC) is a network of actors who collaborate to improve production and add value to the outputs (Asian Development Bank, 2014). Analysis of the VC plays an important role in establishing business strategy and organizational improvement (Iranban, 2019; Ayele et al., 2022). VC analysis allows companies to identify potential sources of competitive advantage and differentiate themselves from their competitors. By understanding where value is created along the chain, companies can reinforce their capabilities and resources to position themselves effectively in the market (Villalba et al., 2023).

The linkages of organizations through VC means that one organization uses the output of another one to produce a more complex product (Khorana et al., 2022). Many new opportunities for many of organizations from under development economies and developing countries is created by VC, because participation means firms are not required to all stages of complex production processes (OECD, 2021).

However, the highly context-specific nature of VC interventions poses a conceptual and practical challenge (Hainzer et al., 2018). In the current uncertain business context, analyzing VC in light of rising protectionist trends attributed to geopolitical tensions (Cattaneo et al., 2010; Khorana et al., 2022). On the other hand, this uncertainty leads to the widespread changes in VCs and their corporate social responsibilities from the design and management percpectives.

1. Ph.D. Candidate, Department of Industrial Management, Rasht Branch, Islamic Azad University, Rasht, Iran
2*. Assistant Professor, Department of Industrial Management, Rasht Branch, Islamic Azad University, Rasht, Iran (Corresponding Author: homayounfar@rashtiau.ac.ir)
3. Associate Professor, Department of Industrial Management, Rasht Branch, Islamic Azad University, Rasht, Iran

The literature attributes such changes to institutional and macroeconomic factors, which include, among others, growing protectionism (Juergensen et al., 2020), sustainability (Pananond et al., 2020), technological advances (Hannibal and Knight, 2018), big data (Strange and Zucchella (2017), and disruptive events with a low probability of occurrence but with a high impact (Khorana et al., 2022). While previous researches have assessed the implementation of VC schemes, there is a lack of cross-comparison among studies from different developing contexts and it has been difficult to identify common drivers for their VC development (Villalba et al., 2023). Moreover, as the operation of VC is based on the interaction of multiple stakeholders at different points in time, the role of non-organizational actors, their interactions, and the decisions that lead to the building of a stronger VC have been less studied.

Porter's (1985) VC model provides a holistic view of business activities and divides them into strategically relevant primary and support activities (Figure 1). Primary activities are concerned with creating a product and bringing it to the customer, whereas support activities assist other activities. According to Porter (1985), primary and supportive activities are not only linked to each other, but also have interconnections with the VCs of external stakeholders such as suppliers, channels, and customers, representing an additional source of competitive advantage (Khorana et al., 2022).

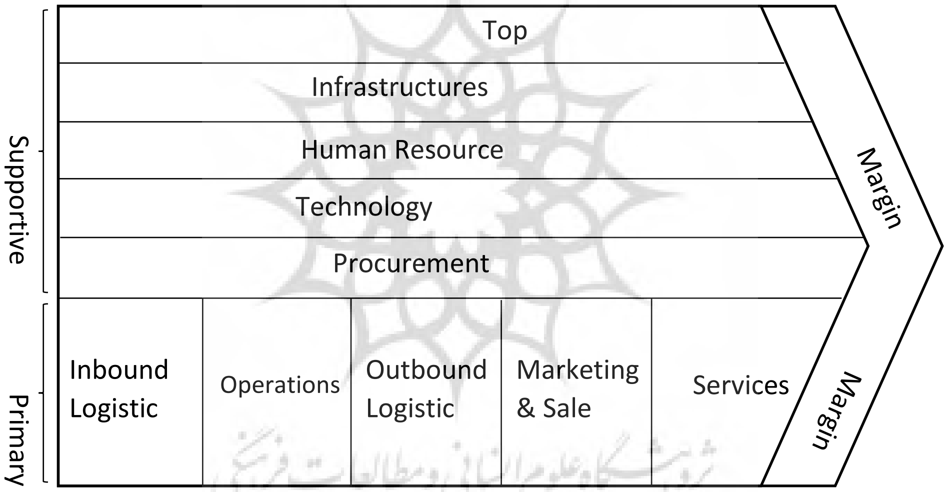

Figure 1. *Schematic value chain*

While VC's practices are strongly linked to their internal functions, there are many external factors which influence supply chain performance. These factors could be categorized into industry and PESTLE factors. PESTLE analysis is a concept used by companies to track the environment they're operating in. PESTLE is a mnemonic which in its expanded form denotes P for Political, E for Economic, S for Social, T for Technological, L for Legal, and E for Environmental. Internal and external environments, constitute the whole environment from many different angles that one wants to check and keep a track.

After network and networking equipment, telecommunications utilities, and retail, pharmaceutical industry is ranked third among the 53 most lucrative industries in the world (Jassbi et al., 2021). Pharmaceutical industry is a strategic industry, due to its extraordinary financial turnover, employment generation and its role in the health system, (Sayyari et al., 2023). Pharmaceutical and related costs in Iran include about 30% of the total cost of health care and nearly 50% of the cost of outpatient health care, it is of main importance in the country's health system. Historical studies show that during the past few decades, despite problems such as imposed war and economic sanctions, providing the medicine needed by the society has always been one of the main concerns of the country (Tavakol et al., 2023a, Tavakol et al., 2023b). This study, analyzed the main drivers affecting on Iran pharmaceutical VC companies based on the fuzzy cognitive mapping (FCM) method. Due to the ability of FCM in analyzing the complex systems with high interactions and under uncertainty of judgments, it is used as the research analytical tool. As Özesmi and Özesmi (2004) mentioned, the main reasons for usefulness of FCM as a decision support tool, include: (1) the ability to allow feedback processes, (2) the ability to deal with many variables which may be not well-defined, (3) ability to model relationships between variables that are not known with certainty, but can be described in fuzzy terms, (4) the ability to model systems where scientific information is limited but expert and/or local knowledge is available, (5) ease and speed with which cognitive maps may be obtained and reach similar results with lower sample sizes as compared to other techniques, (6) ease and speed with which many different knowledge sources can be combined, including expert and local knowledge and, (7) ease and speed of modelling the system and the effect of different policy options. So, it’s a proper tool for analyzing the data.

The reminder of the paper is structured as follows. Section 2 reviews the current literature with the different approaches to study VCs. Section 3 explains the research methodology, data collection, and the analytical approach. Section 4 describes the modelling steps in real world problem and practical findings. Finally, Section 5 concludes with our key results and suggestions.

Literature Review

The concept of the VC was introduced by Michael Porter in his seminal book "Competitive Advantage" in 1985. Porter defined the VC as a series of activities that organizations perform to deliver valuable products or services to customers (Porter, 1985). His framework identified primary activities (such as inbound logistics, operations, marketing and sales, and after sale service) and support activities (including procurement, technology development, and human resource management) that contribute to overall value creation. Since Porter's initial work, researchers have extended and refined the VC concept, leading to various approaches to analyzing VCs (Lambert and Cooper, 2000). One popular approach is the VC mapping technique, which visually represents the sequential activities and interdependencies within a VC. This method helps to identify areas of competitive advantage, inefficiencies, and potential collaboration opportunities. Another approach focuses on the VC configuration, considering factors such as vertical integration, outsourcing, and strategic alliances. Researchers have explored the optimal configuration of VCs to enhance operational efficiency, cost reduction, and responsiveness to market changes. Furthermore, the VC sustainability perspective has gained attention, emphasizing the integration of environmental and social considerations into VC analysis.

In the literature, different approaches are used to analyze VCs, and the impact of VC analysis on business strategy. Villalba et al. (2023) analyzed the role of non-farmer actors including banks, development organizations, agribusinesses, and academia using in depth expert interviews to identify the driving factors for the development of agricultural VC finance (AVCF). Using the Grounded Theory approach, they proposed the Ecosystem Approach as a framework for establishing long-lasting AVCF schemes in developing countries based on three critical solutions: building financial platforms for VC transaction records, implementing bundled services for the VC, and evolving from a VC to a value web approach. The findings introduce six propositions that shed light on key factors for the development and longevity of financing schemes: i) the AVCF Ecosystem, ii) how AVCF schemes emerge, iii) social capital and VC interactions, iv) culture and VC characteristics, v) market risk, vi) transaction costs reduction. We find that AVCF can use social and trade capital to reduce transaction costs and mitigate risks related to quality, prices, and markets.

Low et al. (2023) reviewed the broad literature on MiFAS with a particular focus on implications for food VCs and used thematic analysis to code existing evidence and categories these codes into four major themes: MiFAS value creation, Impacts of the farming environment on value creation, Ecosystem service valuation, and Supply & VC integration. Belton et al. (2021) tracked the impacts of COVID-19 and associated policy responses on the availability and price of aquatic foods and production inputs during 2020, using a high frequency longitudinal survey of 768 respondents in Bangladesh, Egypt, India, Myanmar, and Nigeria. According to the results, impacts on demand for aquatic foods, production inputs, and labor have been longer lasting than impacts on their supply. Survey respondents adapted to the challenges of COVID-19 by reducing production costs, sourcing alternative inputs, diversifying business activities, leveraging social capital, borrowing, seeking alternative employment, and reducing food consumption. Sengupta and Dreyer (2023) studied how digital twin-supported sales and operations planning (S&OP) may be used as an intervention to predict and detect variability across the VC to prevent and reallocate food surplus, to bring the zero-waste VC concept to fruition.

In a literature review, Eisenreich et al. (2022) structured the potential implications of a circular economy along Porter's VC framework and seven overarching main topics are identified. The analyses show that the linear structure of Porter's framework is not sufficient to reflect circular business practices, requiring changes toward a circular and interconnected view. Eora database, Khorana et al. (2022) simulated scenarios to examine Commonwealth countries' participation in global VCs (GVCs) post-COVID. The results show that trade protectionism is likely to impact the supply chains and lead to GVC reconfiguration, which could offer opportunities for the Commonwealth countries and firms to potentially gain following the geographical redistribution of suppliers. Ayele et al. (2022) analyzed the wheat VC in Duna district, Hadiya zone, Southern Ethiopia. The result showed that the actors in the wheat VC have a shaky relationship. According to the findings, flour wholesalers had the highest market margin (18.36%), followed by flour processors (17.70%). The estimated multiple linear regression result revealed that wheat supply is influenced by the quantity of wheat produced, household education level, farming experience, frequency of extension contacts, and lagged market price. Furthermore, wheat producers identified climate variability and low wheat prices as the top two problems in wheat production and wheat marketing, respectively.

By examining the studies conducted on VC in the supply chain, a list of affecting factors is summarized in Table (1):

Table 1.
The affecting factors on value chain

Category	Factors	References
Institutional	Value chain resilience	Muflikh et al., 2021; Rösch et al., 2022
Infrastructures	Financial strength	Brzezina et al., 2016; Dizyee et al., 2017; Zare Mehrjerdi et al., 2020; Barrowclough and Deere Birkbeck, 2020; Muflikh et al., 2021; Gerassimidou et al., 2022

Category	Factors	References
	Recycling capabilities	Barrowclough and Deere Birkbeck, 2020; Zare Mehrjerdi et al., 2020; Gerassimidou et al., 2022;
HRM	Skilled human resources	Zare Mehrjerdi et al., 2020; Aigbavboa and Mbohwa (2020); Nahar et al., 2022
Technology Development	Production technology	Brzezina et al., 2016; Dizyee et al., 2017; Muflikh et al., 2021
	Research and Development	Zare Mehrjerdi et al., 2020
Operations	Operational efficiency	Muflikh et al., 2021
	Non-value-adding activities	Debnath et al., 2023
Outbound Logistics	Transportation/Distribution cost	Zare Mehrjerdi et al., 2020; Cooper et al., 2021; Nahar et al., 2022; Muflikh et al., 2021; Seifermann and Anzeneder, 2022
Marketing & Sale	Medicine price	Nahar et al., 2022; Muflikh et al., 2021; Zare Mehrjerdi et al., 2020; Nahar et al., 2022
Industry Forces	VC governance	Low et al., 2023; Muflikh et al., 2021
Political Factors	Import limitations	Purnomoa et al., 2020
Economic Factors	Cost of raw materials	Zare Mehrjerdi et al., 2020
	Cost of energy	Zare Mehrjerdi et al., 2020
Social Factors	Consumer behavior and social trends	Brzezina et al., 2016; Dizyee et al., 2017; Iacovidou et al., 2017; Purnomoa et al., 2020; Muflikh et al., 2021; Gerassimidou et al., 2022;
Technological Factors	Technological capabilities	Nahar et al., 2022; Gerassimidou et al., 2022; Zare Mehrjerdi et al., 2020
	Internet of Things	Eisenreich et al., 2022
Legal Factors	Government policies	Muflikh et al., 2021; Gerassimidou et al., 2022; Iacovidou et al., 2017; Aigbavboa and Mbohwa (2020); Nahar et al., 2022; Debnath et al., 2023
Environmental Factors	Sustainable waste management	Gerassimidou et al., 2022; Purnomoa et al., 2020; Iacovidou et al., 2017; Debnath et al., 2023; Zare Mehrjerdi et al., 2020
	Environmental concerns about waste disposal	Iacovidou et al., 2017; Muflikh et al., 2021

A systematic review of the VC indicates that studied that have been addressed VC are generally based on quantitative modeling tools. However, these studies strive to simplify the developed model's complexity in order to facilitate understanding and implementation for stakeholders. Using the fuzzy cognitive map helps to bridge the gap between mathematical models and policy-making processes, providing decision-makers with the ability to select desired strategies among different strategies. Additionally, the affecting factors are extracted through a qualitative method (Grounded Theory) which validates the results of the modeling phase. Due to the importance of value chain analysis, its analysis using a mix methodology could be useful for companies to take competitive advantage by making key values.

Research Methodology

This study applied systems approach namely, fuzzy cognitive map, for VC analysis in the pharmaceutical industry. FCM is chosen for its holistic way of analyzing the problem and the potential factors affecting the system and developing improvement strategies. In this research, FCM expert software is used for designing, learning and simulating in fuzzy cognitive modeling. It allows performing WHAT-IF simulations and studying the system behavior through a friendly, intuitive and easy-to-use graphical user interface. FCM expert rely on machine learning algorithms to compute the parameters that might define a model, optimize its network topology and improve the system convergence without losing information which is written in Java language. The research process is described in three phases as follows:

1. Identification of affecting factors on the VC of manufacturing industries using literature review: To determine the dimensions and indicators for research and examine their relationships with each other, a search was conducted in previous domestic studies on the VC. A total of 20 important factors were identified as primary factors within 7 main categories, which are presented in Table (1).
2. Determination of the key factors through expert judgments: In this phase, the identified factors from literature review were distributed among experts in the form of a Delphi questionnaire, and the opinions of each expert were collected as linguistic variables. After replacing them with triangular fuzzy numbers, they were turn into crisp values using the Minkowski equation. Subsequently, the average opinions of all experts were aggregated in the adjacency matrix.
3. Modelling the system interactions using fuzzy cognitive map: In this phase, based on the information collected from the previous phase, the steps of fuzzy cognitive map were carried out to structure the system components. In this regard, the influence, susceptibility, and priority of each factor were examined through the outputs of static analysis. Fuzzy cognitive map was drawn as a graphical model of relationships, and using the activation functions.

In constructing fuzzy cognitive map, the use of experts leads to improving the reliability of the final model (Yaman and Polat, 2009) and enables the utilization of expert knowledge. Although determining the exact number of expert group members is challenging, it is recommended that the researcher be in contact with a small number of experts (for example, three to ten experienced individuals) (Ferreira et al., 2017). Therefore, in the third phase of the research, a group consisting of 14 experts at Sobahan Darou Company, were participated in this study. The criteria for selecting research experts were their theoretical expertise, practical experience, willingness, and ability to participate in the research. All discussions, inferences, and evaluations related to the identification and comparison of factors were determined under consideration of these experts. The data collection tools were interview and questionnaire, where its validity was checked using content analysis.

Fuzzy Cognitive Map

Fuzzy cognitive map (FCM) was first introduced by Kosco (1986) in response to the basic limitations of cognitive mapping. In this method, in order to overcome the difficulty of using crisp numbers to express the intensity of relationships, linguistic variables have been used (Pomagal et al., 2021). The reasoning process of fuzzy cognitive map is based on neuro-fuzzy system and tries to analyze issues related to decision making, modeling and simulation of complex systems (Navas de Maya and Kurt, 2020; Ramirez-Bautista et al., 2020, Izadi et al., 2020). In general terms, FCM consists of a set of neural processing entities called concepts (neurons) and the causal relations among them. The activation value of such neurons regularly takes values in the [0, 1] interval, so the stronger the activation value of a neuron, the greater its impact on the network. Also, connected weights are relevant in this scheme. The strength of the causal relation between two neurons Ci and Cj is quantified by a numerical weight wij ∈ [−1, 1] and denoted via a causal edge from Ci to Cj.

There are three types of causal relationships between neural units in an FCM, being detailed as follows:
If wij > 0 then there is a positive causality, an increase (decrement) on Ci produces an increment (decrement) on Cj with intensity |wij |.
If wij < 0 then there is a negative causality, an increase (decrement) on Ci produces a decrement (increment) on Cj with intensity |wij |.
If wij = 0 then there is no causal relation.

Equation (1) formalizes Kosko's activation rule, with A (0) as the initial state. A new activation vector is calculated at each step t and after a fixed number of iterations the FCM will be at one of the following states: (i) equilibrium point, (ii) limited cycle or (iii) chaotic behavior. The FCM is said to have converged if it reaches a fixed-point attractor, otherwise the updating process terminates after a maximum number of iterations T is reached.

$$A_i^{(t+1)} = f\left(\sum_{j=1, j\neq i}^{M} w_{ji} \times A_j^{(t)}\right) \quad (1)$$

Subsequently, the values Ait+1 and Ait, respectively, provide the value of the conceptual variable Ci at discrete times t+1 and t. In this case, Ajt will be the value of the concept Cj in the t-th iteration of the simulation.

In the equation (1), f (0) denotes a monotonically non-decreasing function to clamp the activation value of each concept to the allowed intervals [0, 1] or [-1, 1]. The functions most extensively used based on literature are depicted as follows:

Bivalent function	$f(x) = \begin{cases} 1, & x > 0 \\ 0, & x \leq 0 \end{cases}$	(2)
Trivalent function	$f(x) = \begin{cases} 0, & x < 0 \\ x, & x = 0 \\ 1, & x > 0 \end{cases}$	(3)
Saturation function	$f(x) = \begin{cases} -1, & x \leq 0 \\ 0, & 0 < x < 1 \\ 1, & x \geq 1 \end{cases}$	(4)
Hyperbolic function	$f(x) = \frac{e^{2x} - 1}{e^{2x} + 1}$	(5)
Sigmoid function	$f(x) = \frac{1}{1 + e^{-\lambda(x-h)}}$	(6)

In the activation functions (2) to (6), t is the repetition or steps of simulation and wji shows the influence value of the conceptual variable Ci from the variable Cj.

Equation (2) shows an inference rule widely used in many FCM-based applications, but it is not the only one possible. Stylios and Groumpos (2004) proposed a modified inference rule, found at Equation (7), where neurons also take into account its own past value. This rule is preferred when updating the activation value of independent neurons, i.e., neurons that are not influenced by any other neural processing entities.

$$A_i^{(t+1)} = f\left(\sum_{j=1, j\neq i}^{M} w_{ji} \times A_j^{(t)} + A_i^{(t)}\right) \quad (7)$$

Another rule proposed in Stylios and Groumpos (2004) is used to avoid the conflicts emerging in the case of non-active neurons. The re-scaled inference depicted in Equation (8), allows dealing with scenarios where there is not information about an initial neuron-state and helps preventing the saturation problem.

$$A_i^{(t+1)} = f\left(\sum_{j=1, j\neq i}^{M} w_{ji}\,(2A_j^{(t)} - 1) + (2A_i^{(t)} - 1)\right) \quad (8)$$

After coding and analyzing the adjacency matrix and checking the static analysis resulting from this matrix, FCM is drawn. Subsequently, in the continuation of the modeling process, FCM implements the model and repeats the simulation based on the principles of the neural network method and using one of the common activation functions (3) to (6) and continues the calculations until the system converges (Venhonshoven et al., 2020; Ramirez-Bautista et al., 2020).

In equation (6), λ is a real and positive number, which determines the slope of the threshold function; x also represents the value of Ai(t) at the equilibrium point. Often, the sigmoid function is used as the activation threshold function; to show that the value of concepts is in the range [0, 1]. In this function, the value of λ is generally assumed to be "1"; This value is an estimate for the linear function and has shown better performance than other functions in various studies (Felix et al., 2017). The simulation process continues until the condition presented in equation (9) is met and the modeled system enters the state of equilibrium or convergence (Falcon and Drosa, 2020). The difference between the next two output values should be equal to or less than epsilon (ε=0.001) (Venhonshoven et al., 2020).

$$\left|A_i^{(t+1)} - A_i^{(t)}\right| \leq \varepsilon \qquad (9)$$

The FCM network can be described using concepts such as density, input degree, output degree and centrality index (Kokinos et al., 2020). Density is an indicator of connectivity and counts the number of existing connections between mapping concepts as a ratio of the number of all possible connections. The input degree (degree of influence) of the concept i is equal to the sum of the values of the column related to the variable i and the output degree (degree of to be influenced) is also equal to the sum of the values of the row related to variable i in the adjacency matrix. The centrality index is also obtained from the sum of the input and output degrees of that concept, as mentioned in equation 10.

$$Cen(C_i) = \sum_{i=1}^{n}\left|w_{ij}\right| + \sum_{i=1}^{n}\left|w_{ij}\right| \qquad (10)$$

In general, using fuzzy cognitive mapping, it is possible to evaluate the impact of concepts on each other, as well as the whole system. By designing "what-if" questions, it’s also possible to simulate different scenarios and evaluate the impact of changes in some concepts on the whole system. The development stages of fuzzy cognitive mapping modeling are presented in eight steps as follows:

Step 1. Identification of the factors related to the problem

Step 2. Evaluation of causal relationships among related factors by experts

Step 3. Evaluation of the causal relationships’ intensity among the factors (concepts). In this step, the experts were asked to determine the causal relationships’ intensity using a linguistic scale (Table, 2).

Table 2.

Linguistic variables and the equivalent fuzzy triangular numbers

Linguistic Variable	Fuzzy Triangular Numbers
Element i has a crucial influence on element j	(0.75, 1, 1)
Element i has high influence on element j	(0.5, 0.75, 1)
Element i has moderate influence on element j	(0.25, 0.5, 0.75)
Element i has low influence on element j	(0, 0.25, 0.5)
Element i has no influence on element j	(0, 0, 0.25)

Indeed, the experts used a 5-point scale from “no influence” to “crucial influence” in order to judge about the influences among value chain concepts. The triangular fuzzy numbers related to each verbal value is then turned into crip values using Minkowski formula (equation 11).

$$D = M + \frac{\beta - \alpha}{6} \qquad (11)$$

In this equation, M is the most likely value, β is the difference between upper and the most likely values and, α is difference between the most likely and lower values in a triangular fuzzy number the in this way, the degree of causality between two concepts will be in the range of [-1, 1]. It should be noted that before determining the relevant intensities, a consensus on the direction (sign) of all system effects was also achieved by experts.

Step 4. Aggregation of the expert opinions. After de-fuzzification of the individual fuzzy influence matrixes, the average of the experts’ judgments, called “aggregated adjacency matrix” will be computed using equation (10)." The elements of the main diameter of matrix are considered equal to zero, which means that no measure leads to its formation.

$$\bar{W}_{ab} = \frac{\sum_{a,b=1}^{k}\left(W_{ab}^{k}\right)}{k}, k = 1,2,3 \dots, n.. \quad (11)$$

Step 5. Developing the fuzzy cognitive map. The analysis of the adjacency matrix from the fourth step, provides important information such as input degree, output degree, centrality index and density of fuzzy cognitive map to analyze the network structure.

Step 6. Implementation of the simulation process. In order to check the dynamic state of the system and using relations (4) and (9), the values of the factors are calculated during the simulation and the new values will repeatedly replace the previous values.

Step 7. Checking the termination conditions. In this step, if one of the conditions presented in relations (11) or (12) is satisfied, it means that FCM has provided the last state of all concepts and this is called a uniform state. Otherwise, step 6 needs to be repeated again. After the convergence of the system, it will be possible to present the final values of the concepts.

Research Findings

This section covers the implementation and results of the methods outlined in the previous section. Based on the review of the recent literature on “value chain”, as well as consultations with industry experts in Sobhan Darou pharmaceutical company through interviews, a total of 14 important factors have been identified. These factors (Table 1) were sent to 14 experts to ensure factors comprehensiveness. When the experts reached a consensus, the evaluation process began through a survey.

After identifying the affecting factors on VC, they must be evaluated by the experts. For this purpose, a questionnaire was designed based on the factors in Table (1); then, the 20 selected factors were placed in the first row and column of the questionnaire’s table, and the experts were asked to determine the intensity of causal relationships among them based on the linguistic variables (Table 2). Since the judgments of the experts were ambiguous and uncertain, the linguistic variables in this study were converted to triangular fuzzy numbers. Next, the fuzzified matrixes of the experts’ judgments were obtained and their average is calculated in form of the "aggregated adjacency matrix" (Table 3) where its values indicate the influence of raw factors on column factors. For instance, the number 0.24 at the intersection of F1 and F2 shows that from the experts’ opinions, the normalized influence of company resilience (F1) on financial strength (F2) is equal to 0.24 which is rather weak.

Table 3.
Aggregated adjacency matrix

Factors		F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	F12	F13	F14	F15	F16	F17	F18	F19	F20
Company resilience	F1	-	0.24	0.08	0.25	0.00	0.07	0.26	0.00	-0.22	-0.19	0.51	0.00	-0.15	0.00	0.19	0.27	0.20	0.00	0.12	-0.09
Financial strength	F2	0.71	-	0.41	0.50	0.63	0.64	0.38	-0.18	-0.32	0.12	0.36	0.00	-0.35	0.00	0.09	0.59	0.52	0.00	0.44	-0.18
Recycling capabilities	F3	0.34	0.26	-	0.00	0.10	0.11	0.57	-0.42	-0.30	-0.29	0.16	0.00	-0.29	0.33	0.00	0.24	0.15	0.34	0.66	-0.33
Skilled human resources	F4	0.57	0.20	0.16	-	0.00	0.55	0.61	-0.43	-0.32	0.15	0.24	0.00	-0.10	-0.20	0.19	0.06	0.17	0.00	0.31	-0.24
Production technology	F5	0.53	0.28	0.36	0.22	-	0.45	0.78	-0.39	-0.17	-0.36	0.17	0.00	0.00	-0.37	0.25	0.76	0.51	0.28	0.30	-0.28
Research and development	F6	0.29	-0.14	0.45	0.11	0.27	-	0.53	-0.33	-0.19	0.20	0.05	0.00	-0.08	-0.11	0.34	0.54	0.22	0.00	0.48	-0.24
Operational efficiency	F7	0.47	0.36	0.22	0.15	0.10	0.14	-	-0.23	0.08	-0.30	0.00	0.00	0.00	-0.35	0.00	0.00	0.00	0.00	0.24	0.00
Non-value-adding activities	F8	-0.64	-0.50	-0.08	0.00	0.00	0.18	-0.84	-	0.31	0.38	-0.15	0.00	0.00	0.00	-0.12	0.00	0.00	0.00	0.22	0.00
Transportation cost	F9	-0.25	-0.35	0.00	0.00	0.00	-0.13	-0.34	-0.27	-	0.26	-0.16	0.00	0.18	-0.25	0.00	0.00	0.00	0.28	0.22	0.34
Medicine price	F10	0.31	0.46	0.22	0.24	0.00	0.49	0.00	-0.18	0.31	-	0.13	-0.28	0.43	0.09	-0.78	0.33	0.25	0.38	0.14	0.00
VC governance	F11	0.61	0.19	0.08	0.16	0.00	0.05	0.29	-0.20	-0.66	-0.12	-	0.00	-0.55	-0.16	0.10	0.05	0.18	0.00	0.28	0.00
Import limitations	F12	0.77	0.38	0.21	0.00	-0.27	0.40	0.00	-0.22	0.00	0.60	-0.27	-	0.51	0.00	0.42	-0.24	0.00	0.73	0.29	0.36
Cost of raw materials	F13	-0.79	-0.47	0.39	0.00	0.20	0.25	-0.15	-0.23	0.35	0.88	0.20	-0.20	-	0.00	-0.24	0.33	0.21	0.57	0.00	0.00
Cost of energy	F14	-0.64	-0.33	-0.15	0.38	0.34	-0.10	-0.36	-0.15	0.51	0.69	0.34	-0.17	0.53	-	0.00	0.40	0.00	0.54	0.44	0.18
Consumer behavior and social trends	F15	0.46	0.24	0.00	0.00	0.09	0.39	0.00	-0.16	0.00	0.55	0.23	-0.25	0.30	0.00	-	0.08	0.00	0.46	0.19	0.16
Technological capabilities	F16	0.65	0.40	0.54	0.35	0.47	0.30	0.82	-0.65	-0.52	0.60	0.20	0.44	0.12	-0.34	0.46	-	0.40	0.24	0.39	-0.32
Internet of things	F17	0.47	0.30	0.09	0.28	0.25	0.11	0.40	0.52	-0.38	-0.25	0.89	0.00	-0.21	-0.32	0.30	0.10	-	0.00	0.26	0.00
Government policies	F18	0.80	0.56	0.15	0.30	0.36	0.61	0.00	0.00	-0.40	-0.59	0.41	0.84	-0.54	-0.66	0.60	0.42	0.29	-	0.50	-0.31
Sustainable waste management	F19	0.32	0.40	0.38	0.12	0.63	0.15	0.15	-0.20	-0.38	-0.12	0.13	0.00	-0.09	-0.35	0.48	0.46	0.00	0.32	-	-0.64
Environmental concerns about waste disposal	F20	-0.45	-0.10	0.30	0.16	0.17	0.27	-0.18	0.00	0.20	0	0.17	-0.30	0.45	0.26	-0.25	0.41	0.00	0.48	0.55	-

In the modeling process, the structure of fuzzy cognitive mapping model was analyzed using the FCM Expert software. The output of FCM static analysis, which is based on the principles of graph theory, was analyzed and the results are presented as degree of input, degree of output and centrality index of the affecting factors on VC of pharmaceutical companies in Iran. The affecting factors are ranked in Table, 4 based on the descending order of the centrality index. It should be noted that the higher the centrality index score of a factor is, the more influence and impact it has on the network and plays a more central role in the fuzzy cognitive mapping.

Table 4.
Ranking the affecting factors on pharmaceutical supply chain

Factors	Indicator	Input	Output	Centrality
Technological capabilities	F16	8.21	5.28	13.49
Government policies	F18	8.34	4.62	12.96
Company resilience	F1	2.84	10.07	12.91
Financial strength	F2	6.42	6.16	12.58
Medicine price	F10	5.02	6.65	11.67
Sustainable waste management	F19	5.32	6.03	11.35
Cost of raw materials	F13	5.46	4.88	10.34
Production technology	F5	6.46	3.88	10.34
Cost of energy	F14	6.25	3.79	10.04
Research and Development	F6	4.57	5.39	9.96
Operational efficiency	F7	2.64	6.66	9.3
Recycling capabilities	F3	4.89	4.27	9.16
Transportation cost	F9	3.03	5.62	8.65
VC governance	F11	3.68	4.77	8.45
Consumer behavior and social trends	F15	3.56	4.81	8.37
Environmental concerns about waste disposal	F20	4.7	3.67	8.37
Internet of Things	F17	5.13	3.1	8.23
Reduction of non-value-adding activities	F8	3.42	4.76	8.18
Import limitations	F12	5.67	2.48	8.15
Skilled human resources	F4	4.5	3.22	7.72

According to the results, "technological capabilities" with the centrality score of 13.49 has the highest interaction with the system. They refer to the ability of companies to adopt and utilize advanced technologies in their operations, which can enhance production efficiency and improve overall performance. Technological capabilities allow for efficient production processes, innovative research and development, and the implementation of digital solutions throughout the VC. Among the other factors, “government policies”, “company resilience” and “financial strength” took the 2nd to 4th place, from the total influence point of view. Government policies/ support has the second most important factor suggests that favorable government policies and support greatly influence the pharmaceutical VC. Governments play a significant role in regulating the industry, providing financial incentives, and creating an enabling environment for pharmaceutical companies. Company resilience measures the ability of pharmaceutical firms to withstand and recover from external shocks or crises. By having robust risk management practices and contingency plans in place, companies can adapt and sustain their operations even under adverse circumstances. The availability of financial resources is vital for pharmaceutical companies to invest in research and development, manufacturing, marketing, and distribution. It is a key determinant of a company's stability and ability to adapt to market changes.

The column related to the degree of output shows the total influence of each concept on other related concepts; In this column, the "government policies/ support", “technological capabilities” and “production technology” with an output grade of 8.34, 8.21 and 6.46, respectively have the highest impact on system factors. The input degree column also provides the total influence of the other concepts on a specific concept. The "company resilience", “operational efficiency” and “medicine price” with the input grade of 10.07, 6.66 and 6.65 has received the greatest influence from the system factors, respectively. Table (4) also provides other information of static analysis of fuzzy cognitive mapping of this research.

Next, the FCM graphic structure of the pharmaceutical VC is presented in Figure (2). In this fuzzy cognitive mapping, the number of 20 concepts are connected by 304 arcs that express the causal relationships between the related concepts. The transfer function is considered “Sigmoid”, the activation rule is “Kosko’s activation rule with self-memory”, and the epsilon (Convergence) index is equal to 0.001.

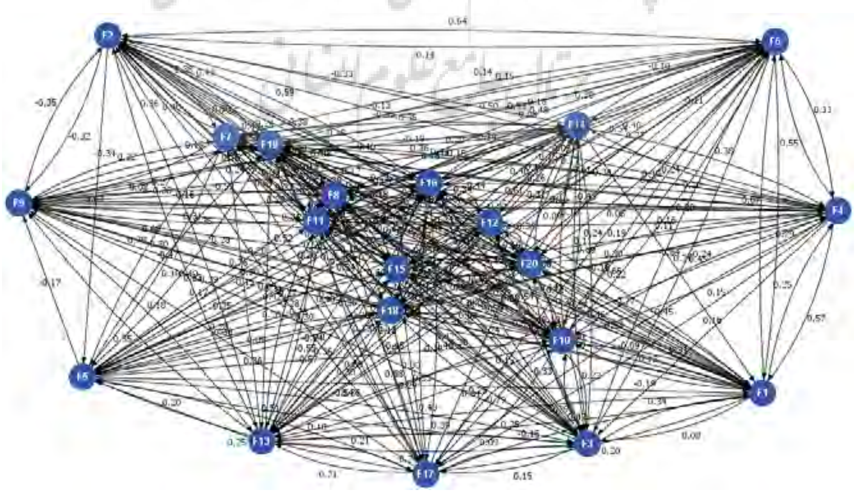

Figure 2. *Graphical structure of the value chain drivers in Pharmaceutical Industry*

In order to visually understand the fuzzy cognitive mapping in Figure (2), after eliminating the causal relationships with weights less than |±0.6|, the corresponding fuzzy cognitive mapping model was again presented in Figure (3); So, only the most important causal relationships are displayed and a more accurate understanding of FCM would be achieved.

As illustrated in Figure 3, technological capabilities (F16), financial strength (F2), import limitations (F12) and government policies (F18) have the highest impact on the system, while company resilience (F1), medicine price (F7) and operational efficiency (F10) received the highest impacts in the system, Finally, model interface allows reasoning using the provided activation values.

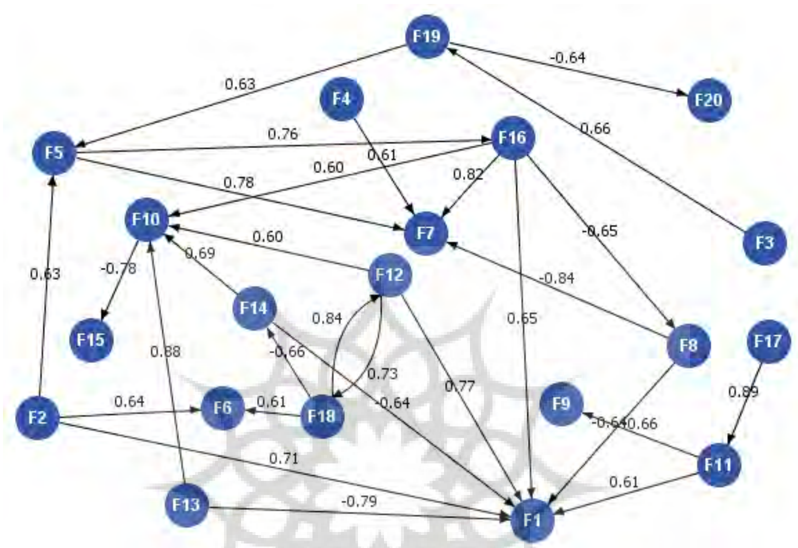

Figure 3. *Graphical structure with important causal relationships*

Before performing the inference process, the user must specify the activation values of input concepts used to activate the FCM-based system. This option will summarize the inference results through a chart and a table with the activation value of concepts at each iteration (see Figure 4).

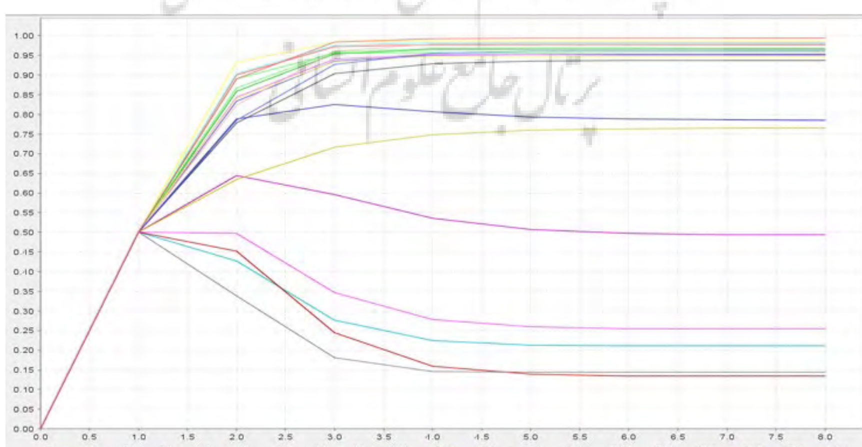

Figure 4. *The graphical interface results*

The graphical interface visualizes the response vector obtained after adjusting the weights. It should be mentioned that the convergence index (ε) in this research considered 0.001.

Based on the results, price of medicines can significantly impact the overall VC. Affordable and accessible medication is crucial for healthcare systems and patients. Factors such as production costs, market competition, and government regulations influence medicine pricing strategies. Sustainable waste management refers to the responsible handling and disposal of pharmaceutical waste to minimize environmental impact. Proper waste management practices are essential for complying with regulations and maintaining sustainable operations. Production technology used in pharmaceutical production plays a vital role in determining efficiency, quality, and capacity. Adopting advanced production technologies can yield cost savings, enhance production speed, and improve product quality. Raw materials or inputs used in pharmaceutical manufacturing can impact the cost and profitability of the VC. Factors such as availability, quality, and pricing of raw materials affect the overall cost structure.

Conclusions and Discussion

Understanding the factors that significantly affect the pharmaceutical VC can help companies to enhance the efficiency and effectiveness of the pharmaceutical VC. Based on the provided centrality index values, it appears that the factors influencing the pharmaceutical VC can be ranked in terms of their importance.:

Based on the results, it's suggested to the top managers of the pharmaceutical industry to make their policies with emphasizing on technological capabilities, company resilience and financial strength. Considering the importance of the critical influencing factors on VC, using the advantages of cooperation with business partners throughout the value chain of the pharmaceutical industry can bring significant improvement. Re-evaluation and optimization of production processes, supply of raw materials, distribution and sales can help to reduce costs and increase speed and quality in the value chain of the pharmaceutical industry. The use of new technologies such as artificial intelligence, cloud computing, and the Internet of Things can significantly improve transparency and productivity in the medicine value chain. Attention to environmental issues and communication with local communities, improving access to medicines and social responsibility can help strengthen the value chain of the pharmaceutical industry. In the meantime, investing in training and development of employees for greater productivity and improving quality and competitive power can bring significant added value.

In order to analyze the value chain more deeply, future researchers can examine the VC as a dynamic system with complicated and inter-related elements which form value chain's behavior based on feedback structures and analyze the impact of different policies on its improvement. The future researches can consider main players of the system as intelligent agents and model the VC using agent-based modeling. The improvement policies either could be analyzed, too. Among the research limitations, using the judgments of Sobhan Darou's experts rather than all of the experts in pharmaceutical industry is more outstanding.

References

Asian Development Bank (ADB), 2014. Bangladesh: Agribusiness Development Project (Project Completion Report No. 33224; 2190-BAN (SF)). Asian Development Bank.

Ayele, A., Erchafo, T., Bashe, A., Tesfayohannes, s. (2022). Value chain analysis of wheat in Duna district, Hadiya zone, Southern Ethiopia, Heliyon, 7 (7), e07597. https://doi.org/10.1016/j.heliyon.2021.e07597.

Belton, B., Rosen, L., Middleton, L., Ghazali, S., Mamun, A.A., Shieh, J., et al. (2021). COVID-19 impacts and adaptations in Asia and Africa's aquatic food value chains. Marine Policy, 129, 104523. https://doi.org/10.1016/j.marpol.2021.104523.

Borrero-Domínguez, C., Escobar-Rodríguez, T. (2023). Decision support systems in crowdfunding: A fuzzy cognitive maps (FCM) approach. Decision Support Systems, 173, 114000. https://doi.org/10.1016/j.dss.2023.114000

Cattaneo, O., Gereffi, G., & Staritz, C. (2010). Global value chains in a postcrisis world: A development perspective. World Bank Publications.

Eisenreich, A., Füller, J., Stuchtey, M., Gimenez-Jimenez, D. (2022). Toward a circular value chain: Impact of the circular economy on a company's value chain processes. Journal of Cleaner Production, 378, 134375. https://doi.org/10.1016/j.jclepro.2022.134375.

Felix, G., Nápoles, G., Falcon, R., Froelich, W., Vanhoof, K. & Bello, R. (2017). A review on methods and software for fuzzy cognitive maps. Artificial Intelligence Review, 52, 1707-1737. https://doi.org/10.1007/s10462-017-9575-1

Ferreira, F. A. F., Ferreira, J. J. M., Fernandes, C. I. M. A. S., Meidute- Kavaliauskiene, I., Jalal, M. S. (2017). Enhancing Knowledge and Strategic Planning of Bank Customer Loyalty Using Fuzzy Cognitive Maps. Technological and Economic Development of Economy, 6, 860-876. https://doi.org/10.3846/20294913.2016.1213200

Hainzer, K., Best, T. and Brown, P.H. (2019). Local value chain interventions: a systematic review. Journal of Agribusiness in Developing and Emerging Economies, 9(4), 369-390. https://doi.org/10.1108/JADEE-11-2018-0153

Hannibal, M., & Knight, G. (2018). Additive manufacturing and the global factory: Disruptive technologies and the location of international business. International Business Review, 27 (6), 1116–1127. https://doi.org/10.1016/j.ibusrev.2018.04.003

Iranban, S.J. (2019). The Effect of Supply Chain Integration on Operational Efficiency and Value Creation. Journal of System Management, 5(2), 107-132.

Izadi, M., Noorossana, R., Izadbakhsh, H., Saati, S., & Khalilzadeh, M. (2020). Z-Cognitive Map: An Integrated Cognitive Maps and Z-Numbers Approach under Cognitive Information. Journal of System Management, 6(2), 81-102. https://doi: 10.30495/jsm.2020.67723

Jassbi, A., Jafari, M., Mahdavi Mazdeh, M., & Maleki, M. (2021). Identifying the Challenges and Discussing about Current Situation of the Iranian Pharmaceutical Industry Based on a Systematic Analysis of Experts Opinion. Journal of System Management, 7(1), 1-20. https://doi: 10.30495/jsm.2021.1931181.1478

Juergensen, J., Guimon, J., & Narula, R. (2020). European SMEs amidst the COVID-19 crisis: Assessing impact and policy responses. Journal of Industrial and Business Economics, 47 (3), 499–510. https://doi.org/10.1007/s40812-020-00169-4

Khorana, S., Escaith, H., Ali, S., Kumari, S., Do, Q. (2022). The changing contours of global value chains post-COVID: Evidence from the Commonwealth. Journal of Business Research, 153, 75-86, https://doi.org/10.1016/j.jbusres.2022.07.044.

Kokkinos, K., Karayannis, V. & Moustakas, K. (2020). Circular bio-economy via energy transition supported by Fuzzy Cognitive Map modeling towards sustainable low-carbon environment. Science of the Total Environment, 721,137754. https://doi.org/10.1016/j.scitotenv.2020.137754

Lambert, D. M., & Cooper, M. C. (2000). Issues in supply chain management. Industrial Marketing Management, 29(1), 65-83. http://doi.org/10.1016/S0019-8501 (99)00113-3.

Low, G., Dalhaus, T., Meuwissen, M. P. M. (2023). Mixed farming and agroforestry systems: A systematic review on value chain implications, Agricultural Systems, 206, 103606. https://doi.org/10.1016/j.agsy.103606.

OECD. (2021). Global Value Chains: Efficiency and Risks in the Context of COVID-19. Retrieved from https://www.oecd.org/coronavirus

Özesmi, U., Özesmi, S. L. (2004). Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. Ecological Modelling, 176 (1), 43-64.

https://doi.org/10.1016/j.ecolmodel.2003.10.027

Pananond, P., Gereffi, G., & Pedersen, T. (2020). An integrative typology of global strategy and global value chains: The management and organization of cross-border activities. Global Strategy Journal, 10(3), 421–443. https://doi.org/10.1002/gsj.1388

Porter, M. E. (1985). Competitive Advantage: Creating and Sustaining Superior Performance. Free Press.

Sayyari, M., CheraghAli, M., & Saeidi, P. (2023). Strategic International Business Innovation:A New Approach in Development of Iran's Pharmaceutical Industry). Journal of System Management, 9(4), 73-84. https://doi: 10.30495/jsm.2023.1980921.1782

Sengupta, S., Dreyer, H. (2023). Realizing zero-waste value chains through digital twin-driven S&OP: A case of grocery retail. Computers in Industry, 148, 103890. https://doi.org/10.1016/j.compind.2023.103890

Strange, R., & Zucchella, A. (2017). Industry 4.0, global value chains and international business. Multinational Business Review, 25 (3), 174-184. https://doi.org/10.1108/MBR-05-2017-0028

Stylios, C. D., Groumpos, P. P. (2004). Modeling complex systems using fuzzy cognitive maps, IEEE Transactions on Systems, Man and Cybernetics – Part A: Systems and Humans, 34(1), 155–162. https://doi.org.10.1109/TSMCA.2003.818878

Tavakkol, P., Nahavandi, B., & Homayounfar, M. (2023a). Analyzing the Drivers of Bullwhip Effect in Pharmaceutical Industry's Supply Chain. Journal of System Management, 9(1), 97-117. https://doi:10.30495/jsm.2022.1966147.1691

Tavakol, P., Nahavandi, B., & Homayounfar, M. (2023). A dynamics approach for modeling inventory fluctuations of the pharmaceutical supply chain in covid 19 pandemic. Journal of Optimization in Industrial Engineering, 16(1), 105-118. https://doi: 10.22094/joie.2023.1966193.1981

Villalba, R., Venus, T.E., Sauer, J. (2023). The ecosystem approach to agricultural value chain finance: A framework for rural credit. World Development, 164, 106177. https://doi.org/10.1016/j.worlddev.2022.106177.

Yaman, D., Polat, S. (2009). A fuzzy cognitive map approach for effect-based operations: an illustrative case. Information Sciences, 179(4), 382–403. https://doi.org/10.1016/j.ins.2008.10.013

Vanhoenshoven, F., Nápoles, G., Froelich, W., Salmeron, J.L. & Vanhoof, K. (2020). Pseudoinverse learning of Fuzzy Cognitive Maps for multivariate time series forecasting. Applied Soft Computing, 95,106461. https://doi.org/10.1016/j.asoc.2020.106461