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Analysis of critical success factors in a food agile supply chain by a fuzzy hybrid decision-making method

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ABSTRACT

In a recent competitive and challenging market, supply chain management has faced many challenges due to rapid technological changes, new products and variable customer tastes. Therefore, supply chain management seems to require more vigilance and speed leading to the formation of the concept of the agile supply chain. Since supply chain management plays a significant role in food industries and due to the specific nature of the food companies as well as the importance of their supply chain agility, the main purpose of the current study is to evaluate and prioritize the success key factors for agile supply chains in food companies. In this regard, a D-ANP method is employed as a hybrid decision-making method considering the Fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP). The results reveal that among 17 factors of success for agile supply chains in these companies, employee skill development, utilizing robust scheduling systems in distribution and process integration are the highest priority.

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1. Introduction

During the last two decades, supply chain management has been raised as one of the key factors of competition and success of organizations and has received much attention from researchers and experts in production and operations management. Answers to important questions such as how to satisfy the customer, develop the business or increase profitability can be found in the improvement of supply chain management. This solution is the cure for poor service, poor communication, incomplete interaction and many other things (Junejo et al., 2022). In the complex, a dynamic and constantly changing markets' environment, companies need to design and adopt strategies to help them keep up with the changing and dynamic conditions of the competitive market leading to improving their performance. In today's global competitive era of supply chains, companies are trying to be more accountable, durable and reliable with value creation and against the rapid changes in the market. Not only can agile organizations experience continuous change, but they can also react to the severe changes required by the market. Therefore, in light of the changing marketplace, the agility of supply chains is critical for the competitiveness of organizations. It can be argued that only agile organizations can survive and compete in the future.

Despite technological innovations and the changing needs of customers in various industries (especially organizations that are related to people's daily needs), it is becoming more intense. In such a situation, the agile approach becomes multifold important. Although the necessity and importance of supply chain agility due to the need for speed of action, responsiveness to customers, ever-increasing changes in the market and consumer needs, etc., in many industries, both scientifically and experimentally, are hidden from anyone (Nozari, Fallah, Kazemipoor, & Najafi, 2021). No, food producing companies should pay high attention to these issues and draw and develop their supply chain. Because these organizations are active in the field of fast consuming products and timely distribution of these products has a high impact on their health. It is clear that having an agile, flexible and responsive supply chain in food manufacturing companies can solve an important part of the problems that threaten organizations today (Nozari and Ghahremani-Nahr, 2021). Therefore, the main goal of this research is how food manufacturing companies can achieve agility in their supply chain. The main goal of this research is to extract and analyze the most important critical success factors and their quantitative analysis in order to effectively implement an agile and safe supply chain in these important industries. Of course, due to the fact that many researches have been conducted on supply chain agility over the years, but due to the importance of the issue in some industries such as food industries that deal with the health and survival of humans (and therefore require more efficient distribution systems) is essential (Aliahmadi et al., 2022). Specific analysis of the key indicators of exclusive success in these industries can provide an effective guide for analyzing job dimensions, especially in this specific industry.

To gain a competitive edge in a changing business environment, companies must align with suppliers and customers for operational efficiency and partner with each other to achieve a level of agility beyond monopolies. Subsequently, agile supply chains are prominent competitive designs. An agile supply chain seeks to enrich and satisfy customers and employees. Therefore, an agile supply chain is able to respond appropriately to the changes that occur in its working environment (Nozari et al., 2019). Companies are faced with rapid technological changes, increasing uncertainty and dynamism in markets, reduced product life cycles and increasing market segmentation in the global environment. Therefore, the organization's ability to quickly adapt to environmental changes and market conditions is considered a necessary issue for their survival (Zhu et al., 2022). According to what was said, agility is the ability to quickly respond to changes and is considered the main factor for the success and survival of today's companies (Aliahmadi et al., 2022). In addition to the importance of increasing the efficiency and effectiveness of the supply chain by improving the integrity of information flow, it is also important to eliminate waste and search for agility in the supply chain and its effect on performance (Pandey, 2022).

There are several ways to improve supply chain performance and simultaneously reduce costs and increase customer satisfaction, in which the prediction of the upstream demand is crucial. In the modern world, companies have faced rapid technological changes, uncertainty and market dynamism, and a decline in the product life cycle. Therefore, the organization's ability to adapt quickly to environmental changes and market conditions is an essential element of their survival. Because food industries do not have a long expiration date, and these products are in the category of products that are perishables, it seems that the agility of supply chains is important for the timely distribution of goods in this industry. The lack of agility and speed in delivery of goods can result in absence of timely product on the market and other consequences leading to losing sales and customer dissatisfaction. Therefore, attention to the agility of supply chains and critical success factors in this industry seems to be necessary. By recognizing and prioritizing these critical success factors, especially in the food industry that deals with people's lives, organizations can strive for the optimization of various processes from purchasing to selling and distribution. It can also be seen what factors should be emphasized more for the implementation of a more agile supply chain. By facilitating the processes and implementing this supply chain, in addition to the fact that organizations can minimize their costs and take steps towards greater productivity, due to timely distribution, people can also purchase with more confidence and as a result All these food health issues of the society are also provided with a higher percentage of confidence.Due to the importance of supply chain agility, in this research, success factors in supply chain agility in food industries are studied using decision-making methods.

In the present study, a combination of fuzzy Decision Making Trial and Evaluation Laboratory (DEMATEL) and Analytic Network Process (ANP) is employed to identify the internal effects of critical success factors in addition to prioritizing the key success factors for an agile supply chain in food industries in a form of a Multi-Criteria Decision Making (MCDM) problem. This research includes six main parts. In the next section, he reviews the literature on the subject, which includes the literature on agile supply chain and the review of supply chain in food industry. In the third part, the analysis of agility factors in supply chain components is presented. The fourth part is related to the research methodology and its implementation steps, and in the fifth part, the research done on the study is described, and finally, in the sixth part of the research, the summary and suggestions for future research are planned. The process of the proposed approach is shown in Fig. 1.

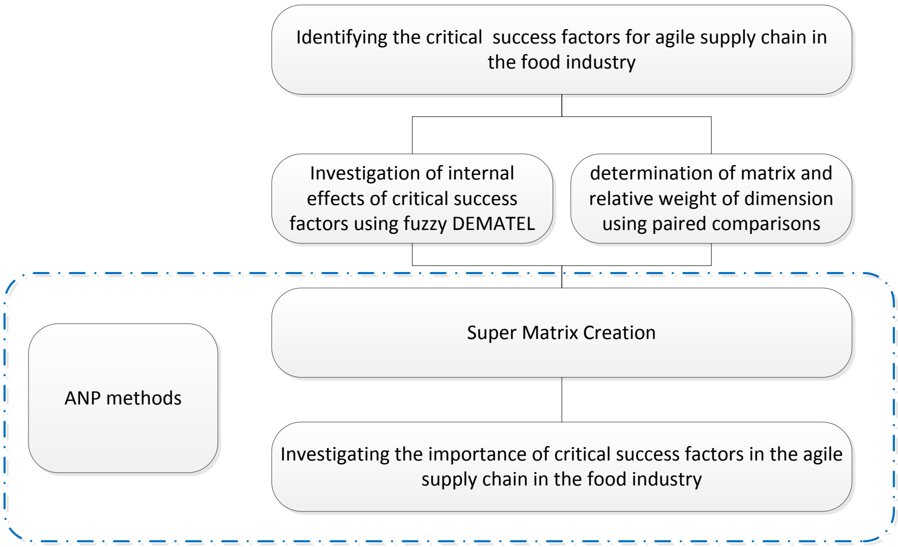


Figure 1. Research process

2. Literature Review

To investigate the impact of agility in supply chain systems in food industries, reviewing the literature for food and consequently about supply chain agility is presented.

2.1 Food Industries

The food industry falls into the category of Fast-Moving Consumer Goods (FMCG) that refer to those products sold rapidly at a relatively low-cost case of a low margin–high volume (Kotler & Armstrong, 2011; Menidjel, Benhabib, & Bilgihan, 2017). The level of involvement can further be considered as to how serious a consumer is in purchasing a product and how much information they require during their decision-making process.

The food industry trades in commodities that are classified as essential products (Nozari, Fallah, Kazemipoor, & Najafi, 2021). Since many people are frequently buying these products, the cost that households pay for food product categories is very significant. Products in the food industry are short-lived and highly manufactured in terms of the volume and variety. The food industry primarily focuses on manufacturing, packaging goods, distributing and some of the fundamental activities including sales and marketing, financing and purchasing (Green, 2016). It is found that the share of the food industries in the gross domestic product (GDP) is significant (Malhotra, 2014). Also, the food environment is unpredictable and known as the most difficult part of the boom because commodities look similar without real competitive advantage and consumers tend to place a lot of values on different brands. In this industry, competition among competitors is always fierce, and the battle for market share continues (Kumar, Kumar Mangla, & Kumar, 2022).

Chapman et al. (2022) evaluated the value chain of the food industry in research that requires improvement and/or improvement in their effectiveness, especially in the range of agility of production processes and big data analysis. In their research, they evaluated the growth of technology and its effects. They emphasized as a key and central part. After the epidemic of the Covid-19 disease in 2020, many studies have also emphasized the importance of the agility of supply chain processes in the food industry. In this regard, Bakalis et al. (2022) examined the opportunities provided by the fourth industrial generation for the purpose of agility in the supply chain. They believe that while the industrial transition to digital and automated food production chains is seen as a response to such challenges, the contribution of Industry 4.0 technology enablers to this goal is not sufficiently well understood. It can help prioritize technology enablers in delivering key aspects of high-performance food production chains. Do et al. (2021) examined supply chain agility in response to unprecedented changes during the UK's COVID-19 crisis. They show how in the wake of the Covid-19 pandemic, each affected item pursued different agile responses through sensing and discovery capabilities. Assessment involves identifying and evaluating opportunities and threats related to a specific supply chain context. Acquisition includes the acquisition, combination and modification of tangible and intangible resources at the company and supply chain level. Second, supply chain transformation is likely if firms and their supply chains develop the resilience to ensure that favorable changes from the crisis continue. Pandey (2022) examined the agile supply chain to manage changing consumer food preferences. They developed a framework using Grounded Theory. For this reason, agility itself can be a competitive advantage and can be of great importance to the industry.

2.2 Supply Chain Agility

Because of today's turbulent and competitive market, the concept of the agility in supply chain systems is the most critical capability for firms and fashion manufacturers to decrease the influence of the short-term changes in demand (Najar, 2022). Indeed, an agile supply chain focuses on responding to unpredictable market and its unpredictable changes as well as capitalizing on these changes through the use of faster and more flexible delivery in terms of product volume and types (Perera, Soosay, & Sandhu, 2019). In this regard, new technologies and tools (e.g., advanced information technologies and electronic data interchange) are employed through which information is quickly transferred to the components of the chain and as a result, better decisions can be made (Christopher, 2000; Brusset, 2016). Wadhwa and Rao (2003) asserted that agility concentrates more on an innovative response when it comes to unpredictable changes. It is also found that agility as an ability of the system with rapidly reacting to the changes can improve the responsiveness of the supply chain (Gunasekaran, Laib, & Cheng, 2008; Yusuf, Gunasekaran, Adeleye, & Sivayoganathan, 2004). However, Gligor (2016) contend that the supply chain agility is not equivalent to a responsive supply chain. Rather, the agility allows firms to operate more efficiently or responsively. Furthermore, Blome et al. (2013) defined agility as a dynamic ability to improve the operational performance of the firm. Also, the supply chain agility can be considered for extending the concept of supply chain flexibility (Gilgor & Holcomb, 2012).

In a research, Azadegan et al. (2019) examined the perspective of organizational learning in response to supply chain disruption. They showed how companies implement response strategies based on near-miss events. This research extends the body of supply chain disruption management to the concept of near loss and explains how the organizational context plays a major role in learning supply chain disruption responses. Braunscheidel and Suresh (2009) indicated that the supply chain agility is the internal and external capability of the firm to respond on time to market changes as well as to potential and actual disruptions. Also, Gilgor et al. (2015) demonstrated that the supply chain agility can affect cost efficiency by meeting ever-changing expectations of customers. It is found that one way to create the supply chain agility is developing cultural competitiveness to which supply chains can detect and fill gaps between customer's desires and offers (Hult, Ketchen, & Nichols, 2002). Fallah et al. (2021) argued that strategic the flexibility and manufacturing flexibility, as main organizational flexibility factors, are critical antecedents to supply chain agility. They showed that both of these factors can positively influence the supply chain; however, among them, the strategic flexibility has a direct and important influence on firm performance. The supply chain agility can be accomplished through the synergies of various kinds of flexibility allowing the firm to respond more effectively to a variable marketplace (Agarwal, Shankar, & Mandal, 2006). Because the agility in a supply chain can lead to fulfilling resource efficiency, improving the level of customer service, decreasing the manufacturing lead-times and increasing the responsiveness of the supply chain (Swafford, Ghosh, & Murthy, 2006; Mohammed, Soroka, & Nujoom, 2019). Nozari et al. (2021) provided a conceptual framework for agile supply chain based on big data analysis in the FMCG industry. They showed that the presence of transformational technologies can play a key role in supply chain agility (Nozari & Ghahremani-Nahr, 2021). Azadegan et al. (2020) in a study analyzed the effects on curbing credit and operational damages caused by supply chain disruptions. They used Simmons' levers of control framework to explain how supply chain involvement in BCM affects a firm's capabilities to contain damage from major SCDs. This research develops and tests hypotheses by analyzing large-scale questionnaire responses from 448 European companies. The importance of the agility of supply chains, especially after the corona virus epidemic, especially in the FMCG industry, became doubly important. For this reason, many researches have been conducted in this field. Al-Omoush et al. (2022) investigated the impact of intellectual capital on supply chain agility and collaborative knowledge creation in response to unprecedented pandemic crises. Saputra et al. (2022) examined the strategic role of digital capability on supply chain agility in the era of COVID-19. They showed that supply chain agility has the greatest impact on company performance. Another study conducted by Mueller et al. (2022) examined supply chain agility under time pressure and temporary supply chains during the COVID-19 pandemic. In this research, an emerging theoretical model has been developed that proposes dynamic capabilities and enables companies to build temporary supply chains in response to a specific need and allows companies to use dynamic capabilities in the short term. Maemunah and Cuaca (2021) investigated the impact of the COVID-19 epidemic on business strategy, information technology, and supply chain agility on company performance in the medical equipment industry. This research showed that business strategy, information technology, and supply chain agility have a positive and significant impact on company performance during the COVID-19 pandemic. The practical implication is that business and information technology strategies by engaging supply chain agility in securing the supply of medical equipment will save companies and society. Panitsettakorn and Ongkunaruk (2021) investigated the improvement of supply chain agility during COVID-19 in health alcohol industry in Thailand. In this paper, solutions are proposed to address the supply chain issues of sanitary disinfectants and can serve as a guide for other cosmetic manufacturers.

Oliveira-Dias et al. (2022) studied the relationships between information technology and lean and agile supply chain strategies. In this study, the aim is to identify and understand the role that information technology plays in these two strategies depending on the way it is conceptualized and whether this is transferred to performance or not. Najar (2022) investigated the innovative performance of agile lean supply chains and the mediating role of dynamic capability, innovation capacity, and relational embeddedness. The findings provide insights into the importance of the mediating role of dynamic capability, relational trust, and R&D management to enhance impact. They created a lean-agile supply chain innovation performance. Aliahmadi et al. (2022) investigated the impact of the presence of big data in the lean-agile supply chain in the pharmaceutical industry. In this research, a framework was presented to investigate the causal relationships of the parameters affecting the agility of the supply chain.

2.3 Fuzzy DEMATEL and ANP

In recent years, decision methods are frequently applied to figure out complex problems. Reviewing the literature shows that DEMATEL with ANP has been used in various successful applications, in which DEMATEL is applied to determine a cause-effect relationship by quantitatively presenting the criteria and ANP is employed to specify the criteria weight for interrelated factors. The approach of DEMATEL was first created at Science and Human Affairs Program of the Battelle Memorial Institute of Geneva. Since then, it has widely been used in many fields of studies, such as evaluating core competencies, decision-making, knowledge management, operations research and technology research (Aliahmadi, Sadeghi, Nozari, Jafari-Eskandari, & Najafi, 2015). The most important feature of the DEMATEL method, which has been utilized in MCDM, is the possibility of specifying the interrelationships between the criteria.

To evaluate decision making, several forms of an integrated method of DEMATEL and ANP are used in recent decades (Chen, Lee, & Yang, 2012; Hu, Lu, & Tzeng, 2014; Büyüközkan & Güleryüz, 2016; Chou, Yang, Dang, & Yang, 2017). More recently, Pedro et al (2018) evaluated the financial and operational performance of airlines through the utilization of combining DEMATEL and ANP, namely DANP, together with a VIKOR model. By applying the DANP method, Chen and Lin (2018) analyzed the key determinants for promoting emerging technologies through institutional intermediaries. Also, Tang (2018) determined critical leadership competencies for junior high school principals through the use of the DANP method. Furthermore, Keliji et al. (2018) investigated the readiness of an Iranian steel company in terms of Six Sigma projects by applying a fuzzy Delphi method and examined the interrelationships between the indicators through the DEMATEL method. To evaluate the food supply chain performance measurement system, Sufiyan et al. (2019) identified the interdependence structure among the performance criteria and indicators by combining the fuzzy DEMATEL with ANP.

Thus, it can be concluded that applying DEMATEL with ANP (i.e., DANP approach) has been employed extensively in recent years. So, in light of this approach, it seems important to evaluate the key factors related to the agile supply chain of the food industry and determine the interrelationship between these factors as well as their sequence. In Table 1, some research conducted in the field of agile supply chain and existing research gaps are shown.

Table 1. Some researches conducted in the studied area

Author(s)	Supply chain agility	Key success factors	Food industry	Multi-criteria decision making	Fuzzy approach	Approach
Hamdani (2022)	✓	×	×	×	×	data mining model
Oliveira-Dias et al. (2022)	✓	×	×	×	×	systematic literature review
Nozari et al. (2022)	×	×	×	✓	✓	Fuzzy Mikhailov approach
Dora et al. (2020)	✓	✓	✓	×	×	Artificial intelligence
Singh & Shabani (2016)	×	✓	✓	×	×	Conceptual Model
Chowdhury et al. (2020)	✓	✓	×	×	×	Interpretive structural modeling method
Yadav & Barve (2015)	✓	✓	×	×	×	Interpretive Structural Modeling
Piya et al. (2020)	✓	✓	×	×	×	structural modeling
Current study	✓	✓	✓	✓	✓	Combined method of DEMATEL and ANP

3. Agility success factors in supply chain structures

Considering the concept of the agility supply chain, the factors of the agility in a supply chain structure are examined in the literature and expert opinions. To this end, based on the agile supply chain model proposed by Swafford et al. (2006), these factors in the essential parts of the supply chain are identified. This model expresses the supply chain agility at three levels of procurement, production and distribution, as shown in Fig. 2 (Swafford, Ghosh, & Murthy, 2006). Subsequently, the underlying factors of the supply chain agility at these three levels are examined.

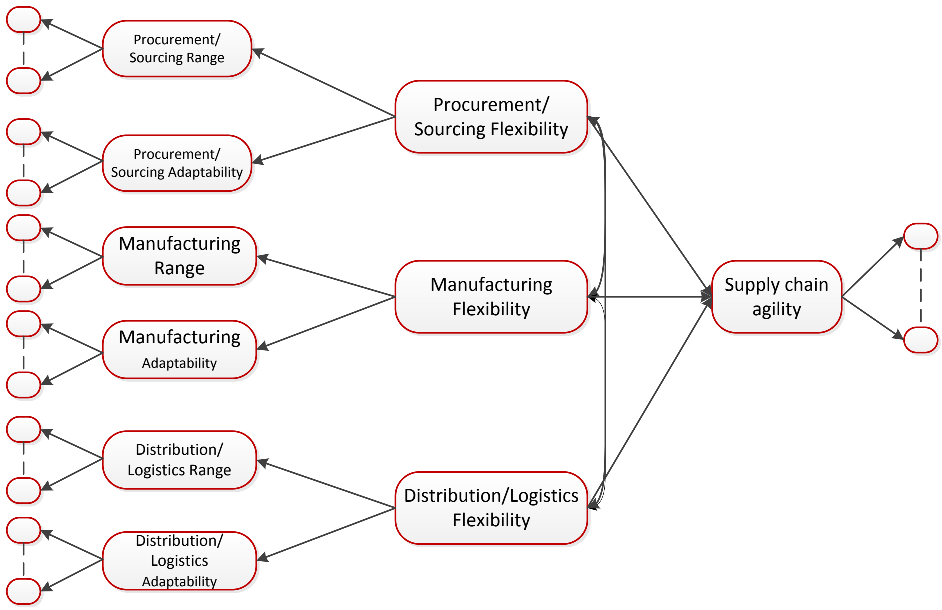


Figure 2. Framework for the supply chain agility

Agility success factors in logistics procurement: Purchasing and supply management is the first part of a supply chain that plays a key role in the supply chain agility. This section deals with suppliers in terms of selecting them, purchasing raw materials from them, managing the transportation of raw materials to manufacturing, communicating with suppliers and having appropriate policies in all of these areas. Key elements of the agility in purchasing management are integrated into Table 2 (Moradi, Razmi, babazadeh, & sabbaghnia, 2019; Beresford & Pettit, 2019; Irfan, Wang, & Akhtar, 2019; Ayoub & Abdallah, 2019).

Agility success factors in production: The agility seeks changes and exploits them as valuable opportunities for growth and prosperity. The agile production criteria are listed in Table 3 (Li, Abtahi, & Seyedan, 2019; Yadav & Barve, 2015; Moradlou & Asadi, 2015).

Table 2. Agility factors in purchasing management

Key factor of the agility	Description
Purchase orders reprogramming	• Provide alternative designs for use in special situations • Use of computerized and automated systems to develop supplier selection plans
Using technology (e.g., ERP) to control and manage procurement	• Control of purchase orders • Manage purchase inquiries • Evaluation and evaluation of raw materials entry and exit
Locating and identifying suppliers to purchase raw materials	• Use standards to select and evaluate suppliers • Maintain and protect the data related to suppliers • Use of electronic and automated ordering system
Modify and change orders	• Variety of products provided by suppliers • Sharing consumer demand information with suppliers • Number of suppliers available for each material • Cost reduction
Empowering suppliers	• Flexible contracts • Frequency collaboration with suppliers • Typical partnerships with suppliers

Table 3. Agility factors in production management

Key factor of agility	Description
Physical flow of production	• Recyclable manufacturing facilities • Waste minimization
Status of employees	• Importance of computer training • Unlimited teaching methods • Motivational environment for learning • Job Rotation
Employee participation	• Enabling staff participation in the decision-making process
Product life cycle	• Product design with minimal price • Designing high-reliability products • Designing more maintainable products • New products
Design improvements	• Design as a continuous activity • The use of new design technologies • Simultaneous Engineering
Production method	• Selection of innovative processes and real technologies • Applying flexible production concepts • Process integration
Production planning	• Short-term planning for quick decisions
Automation	• Flexibility of activities • Computer programming-based production tools
Information technology	• The replacement of physical activities with IT-based activities • The use of multiple communication tools
Time management	• Appropriate information flow • Redesign activities to time reduction
Productivity management	• Using concepts of totality or collectivism to achieve productivity
Outsourcing	• Supplier Selection and Supply Chain Design to Provide Contracting Products

Agility success factors in Distribution Management: Physical distribution management includes managing customer orders, warehouses picking up and distribution in addition to delivery selection. Factors affecting the agility of this part of the supply chain are listed in Table 4 (Ayoub & Abdallah, 2019; Yadav & Barve, 2015; Wu, 2019; Huma & Ahmed, 2022).

As noted in the previous studies, the supply chain agility requires identifying key and influencing factors as well as communicating between them. For this reason, the most important key indicators of supply chain agility in food companies have been identified based on the literature review in addition to the collective opinion of industry supply chain experts.

Table 4. Agility factors in distribution management

Key factor of agility	Description
Flexibility in operations and delivery	Timely delivery
IT capabilities	Maintain distribution plans and customer information Analysis of optimal distribution paths Optimal distribution planning
Reputation Crisis capacity	Customers' growing desire to buy Timely response when customer demand increased
Quality of service	Regular packaging Timely delivery Regular rendering
Operational performance	Executive process planning
Flexible warehouse space	Accurate placement of products in warehouses
Quick access to additional rental warehouse space	Responding to customer needs as production increases
Determination of the flow path of the material	Planning and formulating process strategies from warehousing to delivery Optimal routing

4. Research Methodology

The research method used in this work is a survey type that is one of a variety of descriptive methods and in terms of purpose and focus, it is applicable. Because it seeks to use an uncertain decision-making approach to rank the key success factors in the agile supply chain in the food industry. On the other hand, this research has a field research aspect. Because most of the information contained therein is collected through interviews and questionnaires completed by experts in the field under study. The scope of research is food industries in Iran (i.e., 10 food and dairy companies).

To select the most important key factors for the agility in the supply chain, a panel of expert decision-makers consisting of university professors and senior executives of food companies in Iran are selected for diagnosis and evaluation. Accordingly, the 17 key success factors of the agile supply chain in five categories are identified using research backgrounds and experts' opinions. Fig. 3 illustrates the decision-making network structure for the key determinants of the agile supply chain success in food industries. In the following, the fuzzy decision-making method is used to investigate the effects of key indicators and prioritize these key factors. In classical thinking, the decision maker needs a deep and comprehensive knowledge of the existing conditions to make a decision. But with the emergence of fuzzy thinking, this problem was solved to a large extent and decision makers were able to make decisions in ambiguous situations without the need for complete information and definite numbers by using the techniques presented in fuzzy logic. and fuzzy models have been used. The difference between fuzzy conditions and complete uncertainty is that in the fuzzy condition, the membership function can be defined to measure ambiguous concepts or sets; In case of complete uncertainty, probability function and membership function cannot be defined for the data. Also, in this research, a combined method based on DEMATEL and ANP has been used to analyze decision making. According to the literature on the subject, it can be seen that each of these methods has a high capability and has a proven ability, and they have been used a lot in different researches. Multi-criteria decision-making has always reduced the amount of calculations and increased the accuracy of the results. For this reason, this combined method has been used in this research.

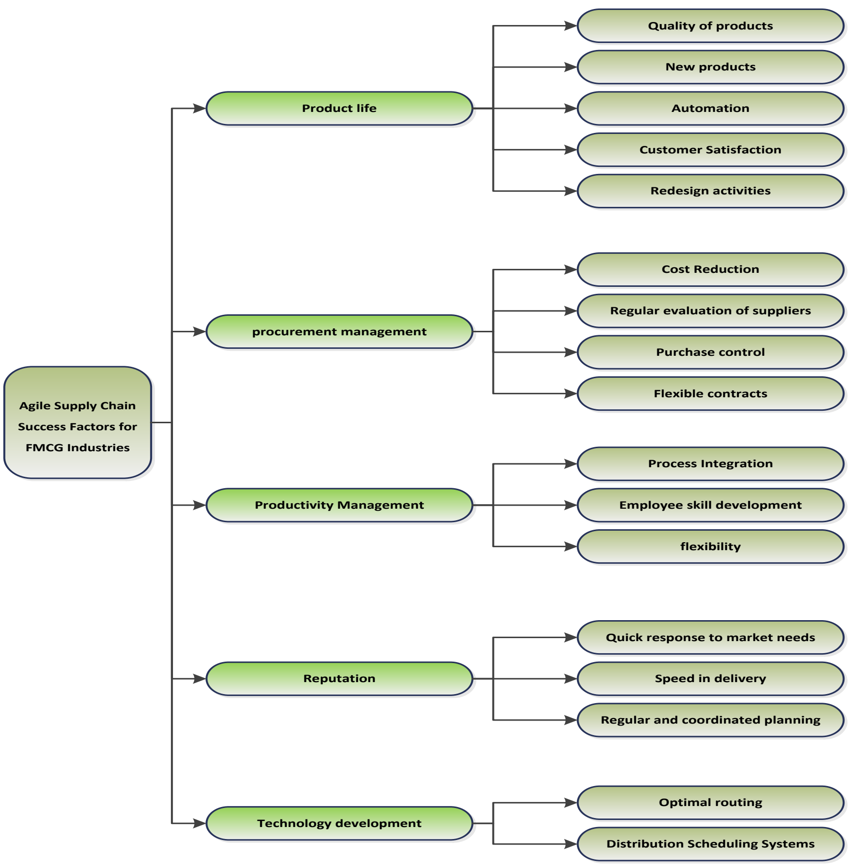


Figure 3. Decision-making network structure for key factors of the agile supply chain success in food industries

4.1 DEMATEL Method

The DEMATEL method has extremely been used in many fields of studies, such as evaluating core competencies, decision-making, knowledge management, operations research and technology research (Aliahmadi, Sadeghi, Nozari, Jafari-Eskandari, & Najafi, 2015). One of the most significant characteristics of the DEMATEL method is the possibility of determining the interrelationships between criteria. After specifying these interactions, the results can be used in other methods (e,g., ANP). The DEMATEL structure and its calculation procedures are summarized as follows:

Step 1: Establishing the direct-relation matrix to measure the relationship between factors i and j requires the comparison scale to be designed according to the following four levels (no influence (0) up to very high influence (4)). The integer score x_{ij}^{k} is given by the k-th expert and shows the degree to which the criterion i affects the criterion j. $n \times n$ matrix A is calculated in Equation 1 by averaging individual expert's scores.

$$a = \frac{1}{H}\sum_{k=1}^{H} x_{ij}^{k} \tag{1}$$

where H is the number of experts.

Step 2: Normalizing the direct-relation matrix. Based on the direct-relation matrix A, the normalized direct-relation matrix D can be obtained by:

$$s = \max\left(\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}, \max_{1\le j\le n}\sum_{i=1}^{n} a_{ij}\right) \tag{2}$$

$$D = \frac{A}{s} \tag{3}$$

Step 3: Calculating the total-relation matrix. Once the normalized direct-relation D is obtained, the total-relation matrix T can be given by:

$$T = D(I - D)^{-1} \tag{4}$$

where I is the identity matrix.

Step 4: Building a causal diagram. The sum of rows and the sum of columns are denoted as vector r and vector c, respectively. The horizontal axis vector (r + c), known as Prominence, represents the importance of the criterion. Similarly, the vertical axis (r − c), known as Relation, divides criteria into a causal group and an effect group. According to the previous statements, the factor is causal or effect if (r − c) is positive or negative, respectively. Thus, the causal diagram can be acquired by mapping the dataset of (r + c, r − c). Vectors r and c can be written by:

$$T = [t_{ij}]_{n\times n} \quad i, j = 1,2,3,\ldots,n \tag{5}$$

$$r = \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = \left[t_i\right]_{n\times 1} \tag{6}$$

$$c = \left[\sum_{j=1}^{n} t_{ij}\right]'_{1\times n} = \left[t_j\right]_{n\times 1} \tag{7}$$

Step 5: Determining the threshold value. In many cases, it is necessary to set threshold value α for explaining the structural relation among factors while simultaneously keeping the complexity of the whole system to a manageable level. Threshold value α is determined by experts to set up the minimum value of the influence level. An influence relationship between two elements is excluded from the map if their correlative value in matrix T is smaller than α.

4.2 Fuzzy Logic

In the real world, many decisions are inaccurate because goals, constraints, and possible actions are not accurately known (Bellman & Zadeh, 1970). When a decision in a fuzzy environment is made, the result of decision-making is highly influenced by subjective judgments that are vague and imprecise. The sources of imprecision are unquantifiable information, incomplete information, non-obtainable information, and partial ignorance (Chen, Hwang, & Hwang, 1992). To find a way to solve the problem of imprecision, Zadeh (1965) introduced a fuzzy set theory as a mathematical method to represent and handle vagueness in decision-making. This theory provided a new mathematical tool for dealing with information uncertainty. Since then, this theory has been well developed and has found many successful applications.

It is difficult to express reasonably the situations that are very complex to define by using conventional quantification. Therefore, applying the linguistic variable concept is necessary for such a situation. Linguistic variables are the variables whose values are words or phrases in a natural language. In calculations procedures, linguistic values can be replaced by fuzzy numbers. In this study, Triangular Fuzzy Numbers (TFN) are used. A triangular fuzzy number $\tilde{A}$ is defined by [(L, M, U)], where L and U are respectively top and bottom boundaries of $\tilde{A}$ as shown in Fig. 4. The fuzzy linguistic scale is shown in Table 5. The membership function is defined by:

$$\mu_{\tilde{A}}(x) = \begin{cases} (x-L)/(M-L), & L \le x \le M \\ (U-x)/(U-M) & M \le x \le U \\ 0 & otherwise \end{cases} \tag{8}$$

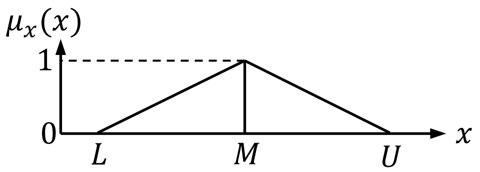


Figure 4. Membership function of triangular fuzzy numbers

Table 5. Fuzzy linguistic scale

Very high influence (VH)	(0.75, 1.0, 1.0)
High influence (H)	(0.5, 0.75, 1.0)
Low influence (L)	(0.25, 0.5, 0.75)
Very low influence (VL)	(0, 0.25, 0.5)
No influence (No)	(0, 0, 0.25)

4.3 Application of Fuzzy Logic in the DEMATEL Method

One of the issues using the DEMATEL method is to obtain the direct effect size between the two factors. The size of these concessions is always obtained by using expert surveys; however, in many cases, people's judgment in decision-making is unclear and cannot be measured using precise numerical values. Therefore, it is necessary to use fuzzy logic in dealing with issues that are ambiguous and inaccurate. To use fuzzy logic in the DEMATEL method, in the first step to measure the relationship between criteria, a decision group of p experts is asked to make sets of pair-wise comparisons by defined linguistic terms as shown in Table 4. After obtaining expert opinions, the fuzzy mean matrix using fuzzy averaging is determined. Subsequently, the existing equations are employed to convert the fuzzy values into the non-fuzzy numbers and matrix of the final mean values is calculated. Therefore, considering *P* responders, the fuzzy matrices will be as much as respondents. Now, the fuzzy mean matrix is calculated and can be given by:

$$\tilde{z} = (\tilde{z}^1 + \tilde{z}^2 + ... + \tilde{z}^p) / p \quad (9)$$

Where $\tilde{z}$ is called the fuzzy primary relation matrix or the intermediate fuzzy matrix, which is represented by:

$$\tilde{z} = \begin{bmatrix} 0 & \tilde{z}_{12} & \cdots & \tilde{z}_{1n} \\ \tilde{z}_{21} & 0 & \cdots & \tilde{z}_{1n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{z}_{n2} & \tilde{z}_{n2} & \cdots & 0 \end{bmatrix} \quad (10)$$

Now by using a deffuzication method, the initial direct-relation matrix can be obtained. To transform TFN numbers to crisp values, CFCS defuzzication method is employed (Opricovic & Tzeng, 2003). If (I_{ij}, m_{ij}, r_{ij}) indicates the effect of criterion i on criterion j in the fuzzy matrix of the direct relation, then the CFCS method can be summarized in the following steps:

The first step is normalization:

$$xl_{ij} = (l_{ij} - \min l_{ij}) / \Delta_{min}^{max} \quad (11)$$

$$xm_{ij} = (m_{ij} - \min m_{ij}) / \Delta_{min}^{max} \quad (12)$$

$$xr_{ij} = (r_{ij} - \min r_{ij}) / \Delta_{min}^{max} \quad (13)$$

where $\Delta_{\min}^{\max} = \max r_{ij} - \min l_{ij}$ (14)

In the second step, the values on the right and left are calculated by:

$$xls_{ij} = xm_{ij} / (1 + xm_{ij} - xl_{ij}) \quad (15)$$

$$xrs_{ij} = xr_{ij} / (1 + xr_{ij} - xm_{ij}) \quad (16)$$

In the third step, the total normalized definite value is calculated by:

$$x_{ij} = [\, xls_{ij}(1 - xls_{ij}) + xrs_{ij} xrs_{ij} \,] / [\, 1 - xls_{ij} + xrs_{ij} \,] \quad (17)$$

and in the last step, the final definitive value can be obtained by:

$$z_{ij} = \min l_{ij} + x_{ij} \Delta_{\min}^{\max} \quad (18)$$

4.4 ANP Method

The ANP is one of the multiple decision-making methods that can be considered as a term of the Analytic Hierarchy Process (AHP) method (Saaty, 1996). This method was proposed to solve the problems of interdependence and feedback between criteria and options in the real world. The AHP method is developed based on paired comparisons.

To decide and select one of the several available options, the AHP method compares them according to the given criteria and calculates the preference of each one over others in each criterion and after weighting the criteria, the one that has the most points is chosen. The major difference between ANP and AHP is that ANP can gain composite weights through a structure, called a super matrix, by communicating between decision levels and characteristics (Shyur & ShihShih, 2006). The super matrix is a segmented matrix that each component shows the relationship between two components or clusters in the system. In the ANP method, the network structure is first explained and the relationships between the different components are determined. For this purpose, literature reviews, expert opinions, or methods (e.g., DEMATEL or interpretive structural model) can be used. After establishing the network structure and determining the different relationships between decision levels, based on the existing relationships, the structure is divided into N subdivisions and pairwise comparisons are made for each segment to form a pairwise comparisons matrix. To check the consistency and reliability of decisions in paired comparisons, the compatibility ratio index is used and calculated by:

$$CR = \frac{CI}{RI} \tag{19}$$

where RI is extracted as a random index from Table 6 and CI refers to the matrix consistency index of the pairwise comparisons. CI is calculated by using the largest eigenvalue λmax and its dimension (n) by the following equation (Pardalos, 2010):

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{20}$$

Table 6. RI index based on a matrix dimension

Dimension	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51

Therefore, if the value CR is less than 0.1, the comparability of the comparisons can be accepted, otherwise, the comparisons should be repeated. After this step, it is necessary to determine the weight of each element. This is possible using the following relationship.

$$\mathrm{Aw} = \lambda_{\mathrm{max}} \mathrm{w} \tag{21}$$

where A is a matrix of paired comparison. Considering N subsets, the structure of the super matrix is as follows:

$$W = \begin{bmatrix} W_{11} & \cdots & W_{1N} \\ \vdots & \ddots & \vdots \\ W_{N1} & \cdots & W_{NN} \end{bmatrix} \tag{22}$$

Also, each of the super matrix elements can be written by:

$$W_{ij} = \begin{bmatrix} W_{i1}^{(j_1)} & \cdots & W_{i1}^{(jn_j)} \\ \vdots & \ddots & \vdots \\ W_{in_i}^{(j_1)} & \cdots & W_{in_i}^{(jn_j)} \end{bmatrix} \tag{23}$$

Finally, after the convergence of values, the elements can be prioritized.

5. Research Findings

In this study, questionnaires are sent to 57 specialists and senior experts in the food supply chain. 50 people completed the questionnaires. By analyzing the results of the questionnaires, first of all, the internal relationships and the impact intensity between the critical factors of the agile supply chain success are determined by the fuzzy DEMETEL method. To examine the effective internal relationships between factors, experts are asked to comment on the extent to which each of the factors has an impact on others based on linguistic criteria and triangular fuzzy positive numbers by Table 4 through pairwise comparisons between the factors obtained from the research.

Then, the effect of factor i on factor j is determined and based on the final result of these pairwise comparisons, the fuzzy direct relation matrix is formed for the main factors and other ones. The results are presented in Tables 7 and 8. Afterwards, the normalized matrix of fuzzy direct relations in addition to the total matrix can be obtained. Tables 9 and 10 show the fuzzy total matrices for principal and sub-factors, respectively.

Table 7. Fuzzy direct relation matrix between the main factors

	H1			H2			H3			H4			H5		
	L	**M**	**U**	**L**	**M**	**U**	**L**	**M**	**U**	**L**	**M**	**U**	**L**	**M**	**U**
H1	0	0	0	0.85	0.65	0.35	0.85	0.7	0.5	0.6	0.45	0.2	0.15	0.65	0.45
H2	0.9	0.7	0.4	0	0	0	0.9	0.75	0.55	0.85	0.65	0.35	0.7	0.45	0.2
H3	0.5	0.25	0.15	0.5	0.25	0	0	0	0	0.55	0.35	0.05	0.45	0.15	0.15
H4	0.95	0.7	0.45	0.95	0.7	0.45	0.9	0.75	0.5	0	0	0	0.8	0.65	0.45
H5	0.9	0.8	0.55	0.95	0.75	0.35	0.9	0.85	0.45	0.15	0.8	0.45	0	0	0

Table 8. Fuzzy direct relationship matrix between sub-Factors

	H11			H12			H…	H51			H52		
	L	M	U	L	M	U	…	L	M	U	L	M	U
H11	0	0	0	0.8	0.55	0.2	…	0.65	0.45	0.15	0.8	0.55	0.3
H12	0.85	0.85	0.45	0	0	0	…	0.85	0.6	0.35	0.7	0.45	0.15
…	…	…	…	…	…	…	…	…	…	…	…	…	…
H51	0.9	0.7	0.45	0.9	065	0.25	…	0	0	0	0.9	0.7	0.45
H52	0.85	0.65	0.35	0.9	0.65	0.45	…	0.2	0.8	0.45	0	0	0

Table 9. Total fuzzy relation matrix for the main factors

	H1			H2			H3			H4			H5		
	L	M	U	L	M	U	L	M	U	L	M	U	L	M	U
H1	0.85	0.35	0.12	1.1	0.49	0.25	1.1	0.75	0.35	1	0.35	0.1	0.91	0.42	0.1
H2	1.25	0.6	0.3	1	0.4	0.1	1.3	0.76	0.4	1.1	0.5	0.32	0.3	1	0.23
H3	1.1	0.23	0.1	0.76	0.25	0.01	0.75	0.23	0.01	0.7	0.24	0.3	0	0.65	0.1
H4	1.4	0.55	0.5	1.3	0.6	0.45	1.4	0.7	0.5	1	0.4	0.23	0.2	1.2	0.3
H5	1.2	0.74	0.45	1.1	0.65	0.4	1.5	0.8	0.55	1.1	0.7	0.34	0.8	0.5	0.3

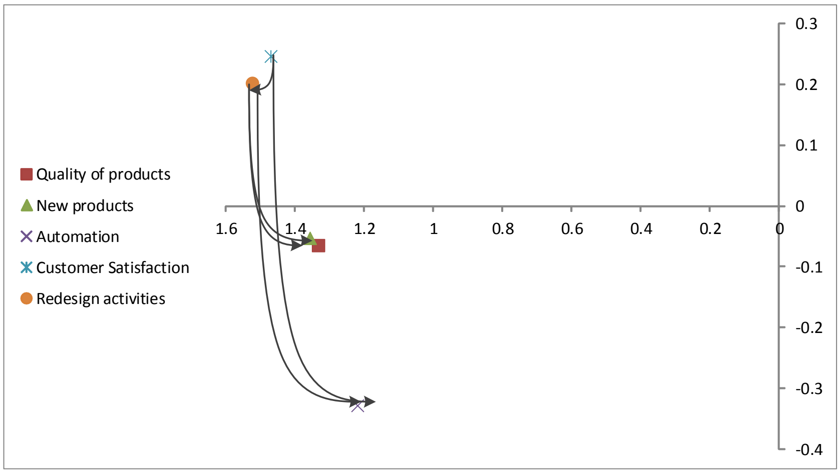
Table 10. Total fuzzy relation matrix for sub-factors

	H11			H12			H…	H51			H52		
	L	M	U	L	M	U	…	L	M	U	L	M	U
H1	0.16	0.08	0.05	0.23	0.15	0.08	…	0.2	0.12	0.08	0.23	0.12	0.06
H2	0.2	0.14	0.06	0.2	0.1	0.04	…	0.2	0.14	0.06	0.23	0.12	0.06
H…	…	…	…	…	…	…	…	…	…	…	…	…	…
H4	0.2	0.15	0.11	0.2	0.13	0.1	…	0.15	0.1	0.05	0.23	0.1	0.1
H5	0.25	0.15	0.1	0.24	0.13	0.1	…	0.2	0.17	0.11	0.19	0.1	0.06

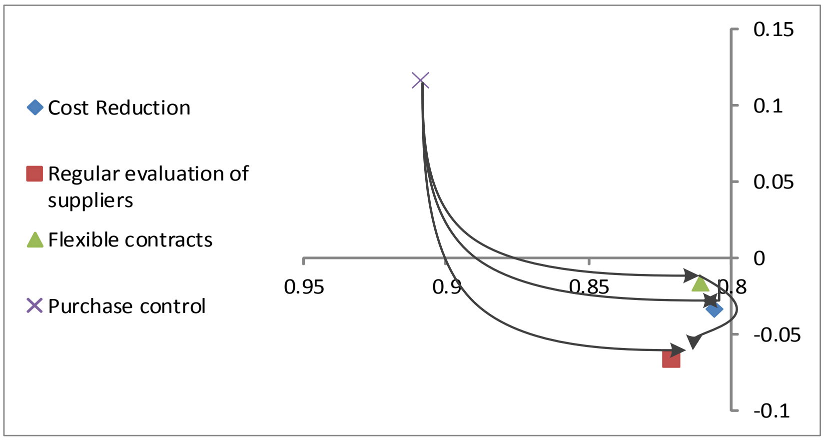
To compile the relationship map, the sums of the columns and rows elements of the total matrix are computed (Equations 6 and 7), as given by Table 11. Factors that have a positive $(r - c)$, are influential and factors with the negative amount of this subtraction are influenced by other factors. Finally, the causal relationships are plotted through Cartesian coordinate systems, by drawing of $(r + c)$ versus $(r - c)$ coordinates, as illustrated in Fig. 5. As can be seen, Figs. 5(a) to 5(e) describe the internal effects of sub-factors of product life, procurement management, productively, reputation and technology development, respectively. Also, Fig. 5 demonstrates the internal effects of critical success factors of the agile supply chain. Table 12 concisely represents the super matrix structure, achieved from the ANP method. Moreover, the overall weight and final ranking of factors using the ANP method are described in Table 13. As can be found from this table, productivity management is the top priority item among critical success factors of the food agile supply chain, followed by technology development and product life items. Furthermore, the item of employee's skill development occupies the first rank of all critical sub-factors in food industries followed by sub-factors of distribution scheduling systems as well as process integration.

Table 11. Results of the calculations of the effect of factors

Factors	*r*	*c*	*r+c*	*r-c*
Product life	3.803	2.438	6.241	1.365
Quality of products	0.632	0.698	1.331	-0.066
New products	0.652	0.705	1.357	-0.053
Automation	0444	0.773	1.217	-0.329
Customer satisfaction	0.857	0.611	1.468	0.246
Redesign activities	0.862	0.66	1.522	0.202
Procurement management	3.277	2.98	6.256	0.297
Cost reduction	0.386	0.42	0.806	-0.034
Regular evaluation of suppliers	0.377	0.444	0.821	-0.066
Flexible contracts	0.397	0.413	0.811	-0.016
Purchase control	0.513	0.397	0.909	0.116
Productivity Management	1.605	3.675	5.28	-2.07
Process Integration	0.227	0.234	0.661	-0.007
Employee skill development	0.255	0.235	0.49	0.02
flexibility	0.241	0.254	0.495	-0.013
Reputation	3.577	2.783	6.36	0.794
Regular and coordinated planning	0.405	0.349	0.754	0.056
Speed in delivery	0.331	0.333	0.664	-0.002
Quick response to market needs	0.277	0.331	0.608	-0.053
Technology development	2.767	3.153	5.92	-0.386
Distribution scheduling Systems	0.27	0.273	0.543	-0.003
Optimal routing	0.283	0.28	0.563	0.003



(a)



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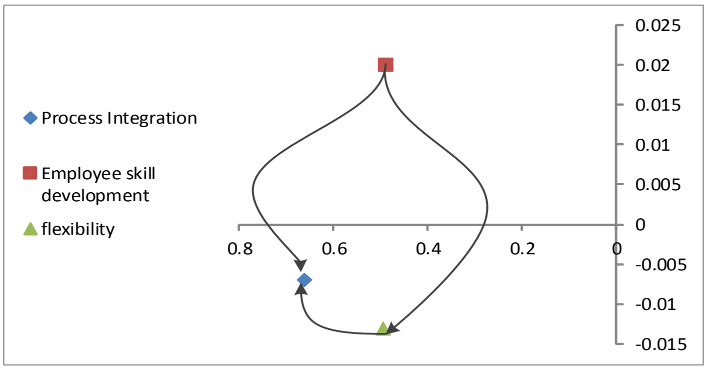

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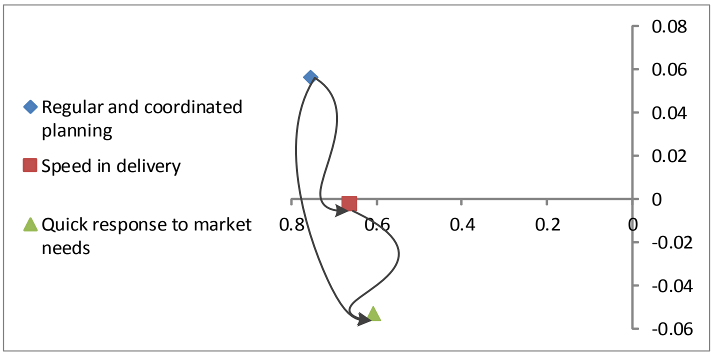

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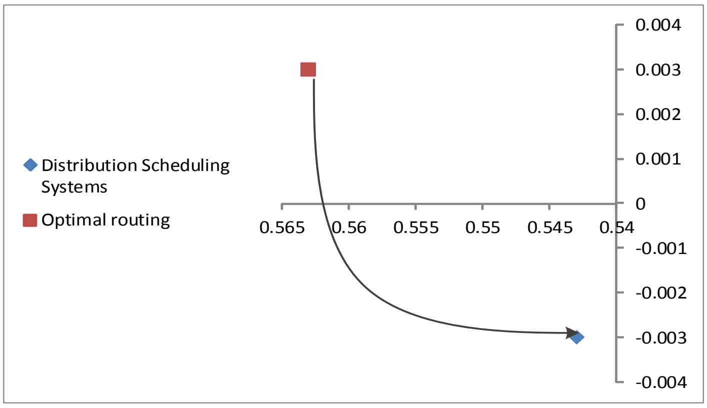
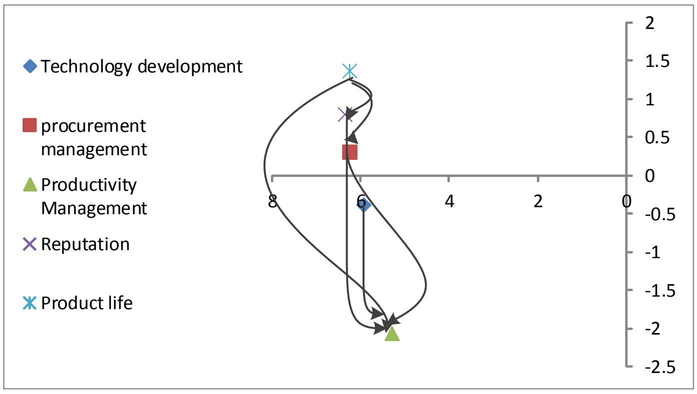


(e)



(f)

Figure 5. Network of influential relationships

Table 12. Defuzzyfied super matrix shown in the compressed form

	H11	**H12**	**H13**	**H[1]…**	**H52**
H11	0.0217	0.0355	0.0345	…	0.0865
H12	0.0333	0.0223	0.0366	…	0.0775
H13	0.0301	0.0342	0.0246	…	0.0903
H14	0.0328	0.0324	0.0355	…	0.0834
H15	0.0336	0.0321	0.0357	…	0.0834
H21	0.0475	0.0435	0.0539	…	0.0860
H22	0.0436	0.0467	0.0605	…	0.0823
H23	0.0462	0.0436	0.0584	…	0.0834
H24	0.0477	0.0466	0.058	…	0.0845
H31	0.0443	0.0351	0.0494	…	0.0874
H32	0.0327	0.0372	0.0388	…	0.0828
H33	0.0404	0.044	0.0402	…	0.0803
H41	0.0447	0.0345	0.0467	…	0.0928
H42	0.0427	0.0452	0.0532	…	0.0914
H43	0.0452	0.0434	0.0456	…	0.0942
H51	0.0469	0.0465	0.0486	…	0.724
H52	0.0454	0.0446	0.0478	…	0.0461

Table 13. Weights and final ranking of factors using the ANP method

Factors	**Final weight**	**Final rank**	**Final weight**	**Final rank**	**Sub-factor**
Product life	0.2027	3	0.0726	6	Quality of products
			0.0406	15	New products
			0.0452	13	Automation
			0.0363	17	Customer satisfaction
			0.0384	16	Redesign activities
Procurement management	0.1936	4	0.0485	11	Cost reduction
			0.0499	9	Regular evaluation of suppliers
			0.0462	12	Flexible contracts
			0.049	10	Purchase control
Productivity management	0.2582	1	0.0819	3	Process integration
			0.0846	1	Employee skill development
			0.0665	7	Flexibility
Reputation	0.1645	5	0.0757	5	Regular and coordinated planning
			0.0806	4	Speed in delivery
			0.0601	8	Quick response to market needs
Technology development	0.2122	2	0.083	2	Distribution scheduling systems
			0.041	14	Optimal routing

By reviewing the literature on the subject and the researches conducted (Table 1) and comparing the results obtained from the current research, it can be seen that the prioritization of the critical success factors in the agile supply chain has many similarities, but in some cases there are differences due to the nature of the food products. have. For example, the development of human resources has the highest priority in all research conducted in various industries. But in the field of food industry, due to the time windows of food distribution and the nature of perishability, the timing of distribution systems is very important. The speed of delivery and distribution on time is also one of the main emphases in the critical factors of success in the agility of the supply chain of the food industry. While the review of other researches in the literature shows that in some industries such as the electronics industry, this item has a lower priority. Also, the literature review and similar studies show that factors such as supplier evaluations have a high priority in all industries and in order to create and implement an agile supply chain, more attention should always be paid. In general, the results of this research show a good overlap with the emphasis of experts active in the field of supply chain in the food industry.

The results of the present research compared to the previous research (research conducted on FMCG industries) show that the key success indicators for supply chain agility, in addition to having a high overlap in different industries, in the food industry due to their importance and nature in food products, emphasis is placed on the timing of distribution and the ability of employees to provide services within time windows. While in many other industries, such as the automotive industry, the emphasis of agility is on timely supply and production systems. A correct understanding of these parameters and priorities presented in this paper can provide an effective guide for the implementation of lean, agile, and high-resilience supply chains.

6. Conclusion

Agile supply chain access varies according to the nature of the products and their characteristics. Therefore, the key factors related to the agile supply chain need to be identified and the relationship between these factors as well as the sequence of those factors should be determined. In the current study, the main factors of the agile supply chain success were selected through reviewing the literature and considering the experts' opinions. After the approval of experts, the statistical population of these 17 factors was investigated in five categories, using a fuzzy DEMATEL method as well as network analysis to determine how these factors relate and sequence. The results revealed that the three factors of employee skill development, utilizing robust scheduling systems in distribution and process integration, are fundamental foundations of the agile supply chain in food industries. Therefore, it was found that food organizations should utilize the training needs of their employees to develop and grow their capability to achieve higher agility and develop the use of technology tools for well-distributed and timely distribution. It should be noted that the network structure presented in this study was purely for food companies and has been formulated based on expert opinions in this field. Various indicators (e.g., environmental conditions, competitors, technologies, and the nature of the goods) have contributed to this structure.

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