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# Intuitionistic Fuzzy Cognitive Map Based Analysis of Supply Chain Risks

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**Abstract.** Supply chains (SCs) are network-like structures and gigantic systems. Such systems are complex and multifaceted. Therefore, they contain many components and risk factors that are directly or indirectly related to each other. The importance of SCs, which has always been important for companies, is increasing day by day. Therefore, it is vital to focus on supply chain management (SCM) and the risk factors encountered in this management process. Plus, the investigation of the cause-effect relationships, evaluation, and analysis of these factors hold a critical role for SCM. Accordingly, this study aims to reveal the risk factors that should be considered in SCM and analyze these factors. Moreover, the causal relationships of these risk factors are aimed to be revealed. For this purpose, Cognitive Map (CM) approach is utilized. The classical CM approach is expanded to the intuitionistic fuzzy (IF) environment and used as the IFCM approach to eliminate the uncertainty and intuition involved in real-life problems and decision-making processes. SC risk factors' importance degrees and causal relations between the factors are displayed and visualized.

**Keywords:** Supply chain, supply chain risks, supply chain risk management, intuitionistic fuzzy cognitive map.

## 1 Introduction

Nowadays, manufacturing supply chains are disposed to be composed of global, complex relationships and flow between tens and hundreds and thousands of geographically dispersed companies and plants. A supply chain has various members such as facilities, distributors, retailers, suppliers, and their suppliers, installation internal and external logistics providers, and financial institutions [1]. The management of such a structure with many components is crucial. Supply chain management (SCM) is a structure that aims to integrate the management and resource control and flow and oversight of the entire system with multiple suppliers [2]. However, SCM is incorporated with risk man-

agement. SCM can be defined as managing risks raised from coordination and collaboration between supply chain members to ensure profitability and sustainability [3]. SC risk management (SRCM), having an influential role in managing business processes and supply chain risks, has many risk sources such as process, control, demand, supply, and environment. Therefore, this study proposes an evaluation framework for supply chain risk analysis and investigates the supply chain risks. The cognitive Map (CM) approach [4] is utilized to analyze these risks with the relationship assumption between criteria. To eliminate the uncertainty, intuition due to human perception, and hesitancy in real-life problems and decision-making processes, the classical CM approach has been expanded to an intuitionistic fuzzy (IF) environment [5]. Hence, the CM is applied as IFCM in this study. A case study is conducted to validate the proposed model in a manufacturing company in Turkey. Importance degree of risks are obtained, and IFCM models of SRCM are visualized.

This study consists of the following sections: Section 2 gives a brief literature survey. Section 3 illustrates the IFCM method. The conducted case study is provided in Section 4 followingly. Finally, the research is concluded in Section 5.

## **2 Literature Review**

SCM is the management of the goods by the flow of finance and information within the network structure of organizations aiming to produce and deliver services or products for customers. Coordination and cooperation of different activities and processes between various functions such as purchasing, logistics marketing, finance and information flow, sales, production, production design are conducted within the network [3].

The SC performance is intrinsically unpredictable. Therefore, managers are often in search of safety measures to be protected from unforeseen situations. In the supply chain process, more efforts are made to check order status frequently. Moreover, distributing necessary inventory and determining the confidence interval of supply times are essential to speed up orders and keep the supply chain performance high. Furthermore, these stocks hide potential hazards until a severe problem arises between the partner due to limited information sharing. This prepares a sub-structure that leads to the formation of risk sources. These risk sources, including delays, disruptions, financial forecasting, intellectual property, purchasing, customers, inventory, and capacity [6], may arise from internal and external supply chains.

This study assumes the existence of relationships between criteria contrary to the principle of criteria independence. This assumption forms the basis for the use of multi-criteria decision-making techniques. The IFCM approach deals with the causal relations

between the criteria considering intuition and hesitation. It has a dynamical behavior, and therefore, different scenarios can be conducted for future conditions.

Various studies are dealing with SC risks in the academic literature. A stochastic model was proposed for risk management in global supply chain networks [7]. Supply chain risks are determined in the automotive and electronic industries, and SCRM implementation is emphasized [8]. The performance-based evaluation was performed under the impact of SCRM [9]. Table 1 shows some studies based on SC risks in academic literature.

**Table 1.** Some SC risks-based studies in the academic literature

Objective of the Study	Source
To make performance-based evaluation under the impact of supply chain risk management.	[9]
To examine that the research developments in supply chain risk management (SCRM).	[10]
To show the need for supply chain risk management as a management function.	[11]
To determine the suited techniques for risk assessment in complex environments in the aspect of the supply chain.	[12]
To investigate the assessment of operational risks-based supply chain.	[13]
To examine the efficiency to develop a model in the aspect of supply chain risk management.	[14]
To emphasize the lack of definition of risk in the perspective of the supply chain in literature.	[15]
To research the effect of visibility and risk on cost in the supply chain.	[16]
To reduce the risk mitigation in the supply chain with a proposed procedure.	[17]

However, there is a limited number of studies using IFCM applications in the literature concerning both SC and SC risks. In these studies, the SC configuration criteria were evaluated using IFCM [18]. A model was developed and analyzed using the IFCM method for sustainable hospital SCM [19]. The IFCM method was used based on a sustainable SCM framework for higher education laboratories [20]. Risks are analyzed concerning the digital supply chain [21]. Hence, this study utilizes the IFCM approach to analyze supply chain risks.

### 3 Proposed Methodology

This section briefly explains intuitionistic fuzzy sets. Following this, the proposed methodology is to be presented.

#### 3.1 Intuitionistic Fuzzy Sets

IF sets were proposed by Atanassov in 1986 [5], and they can deal with obscurity, intuition, and hesitancy [22]. An IF set can be indicated in a finite set as  $A = \{ \langle x, \mu_A(x), \nu_A(x) \rangle \mid x \in X \}$  where  $\mu_A(x), \nu_A(x) : X \rightarrow [0, 1]$   $\mu_A(x)$  and  $\nu_A(x)$  membership and non-membership functions, respectively and here,

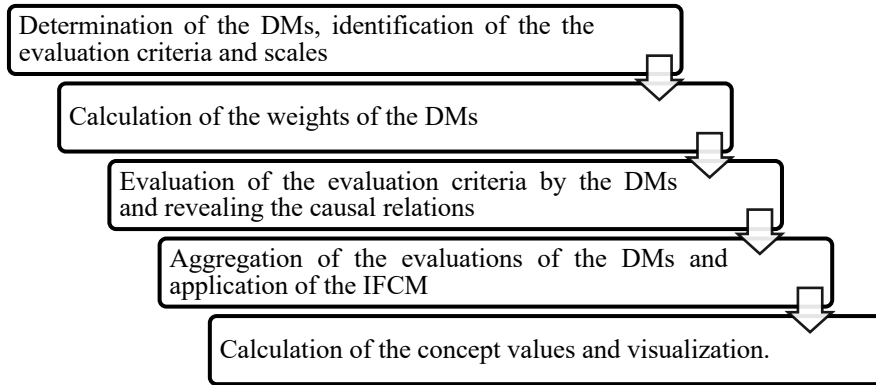
$$0 \leq \mu_A(x) + \nu_A(x) \leq 1. \quad (1)$$

The third component of an IF value which is  $\pi_A(x)$  deals with hesitancy.

$$\pi_A(x) = 1 - \mu_A(x) - \nu_A(x) \text{ where } 0 \leq \pi_A(x) \leq 1, \forall x \in X. \quad (2)$$

#### 3.2 Intuitionistic Fuzzy Cognitive Map Approach

Kosko proposed FCMs, which are network-like structures in 1986 [23], and these structures have causal relationships. Plus, they allow scenario analysis based on their dynamical behavior [24]. FCMs, consisting of nodes, arcs, and their weights, are based on experts' opinions. They are signed weighted graphs [24]. Since real-life problems and decision-making processes include uncertainty, hesitation, and intuition, fuzzy sets [25] may be insufficient to model and solve such issues. Therefore, FCM is extended to IF sets, and it is applied as IFCM [26].



**Fig. 1.** Computational steps of the IFCM approach

The third component of the IF sets deals with hesitancy in decision-making processes. Computational steps of the IFCM approach presented in Fig. 1 are given as follows [26]:

**Step 1:** Determine the DMs, identify the evaluation criteria and scales.

**Step 2:** Obtain the weights of the DMs. The weight of the  $k^{th}$  DM ( $\lambda_k$ ) is calculated by Eq. (3) adopted from Boran et al. [15] using linguistic terms indicated in Table 2.

**Table 2.** Linguistic terms to rate the DMs [22, 27].

Linguistic terms	IF values ( $\mu, \nu, \pi$ )
Very Unimportant	(0.100, 0.800, 0.100)
Unimportant	(0.250, 0.600, 0.150)
Medium	(0.500, 0.400, 0.100)
Important	(0.750, 0.200, 0.050)
Very Important	(0.900, 0.050, 0.050)

$$\lambda_k = \frac{\left( \mu_k + \pi_k \left( \frac{\mu_k}{\mu_k + \nu_k} \right) \right)}{\sum_{k=1}^l \left( \mu_k + \pi_k \left( \frac{\mu_k}{\mu_k + \nu_k} \right) \right)}, \quad \sum_{k=1}^l (\lambda_k) = 1 \quad (3)$$

**Step 3:** Obtain the judgments of DMs on each concept. Causal relationships and the degree of causalities are determined using the linguistic scale given in Table 3.

**Table 3.** Linguistic terms for the degree of causality [26].

Linguistic terms	IF values ( $\mu, \nu, \pi$ )
Negatively Very Strong (NVS)	(0.000, 0.950, 0.050)
Negatively Strong (NS)	(0.050, 0.900, 0.050)
Negatively Medium (NM)	(0.250, 0.700, 0.050)
Negatively Weak (NW)	(0.350, 0.600, 0.050)
Zero (Z)	(0.500, 0.500, 0.000)
Positively Weak (PW)	(0.600, 0.350, 0.050)
Positively Medium (PM)	(0.750, 0.200, 0.050)
Positively Strong (PS)	(0.900, 0.050, 0.050)
Positively Very Strong (PVS)	(0.950, 0.000, 0.050)

**Step 4:** Construct the aggregated weight matrix. Individual evaluations of the DMs are combined into a group decision matrix using the intuitionistic fuzzy weighted averaging (IFWA) operator proposed by Xu [28] indicated with Eq. (4).

$$w_{ij} = IFWA_{\lambda} \left( w_{ij}^{(1)}, w_{ij}^{(2)}, \dots, w_{ij}^{(k)} \right) = \lambda_1 w_{ij}^{(1)} \oplus \lambda_2 w_{ij}^{(2)} \oplus \dots \oplus \lambda_k w_{ij}^{(k)}$$

$$= \left( 1 - \prod_{k=1}^K (1 - \mu_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^K (v_{ij}^{(k)})^{\lambda_k}, \prod_{k=1}^K (1 - \mu_{ij}^{(k)})^{\lambda_k} - \prod_{k=1}^K (v_{ij}^{(k)})^{\lambda_k} \right) \quad (4)$$

**Step 5:** Apply IFCM [26]. IFCM equation is applied to find the value of each criterion. Eq. (5) equation is used to calculate concept values at each iteration until convergence.

$$A_i^{(t+1)} = f \left( A_i^{(t)} + \sum_{j \neq i, j=1}^n A_j^{(t)} (\mu_{ij}(w) - \pi_{ij}(w)) \right) \quad (5)$$

where  $A_i^{(t+1)}$  indicates the value of the concept  $C_i$  at iteration  $(t+1)$ ,  $f(x)$  shows the threshold function, which is sigmoid  $\left( f(x) = \left( \frac{1}{1 + e^{-\alpha x}} \right) \right)$ . Here, the growth rate is set to -0.1 ( $\alpha = -0.1$ ).  $A_i^{(t)}$  represents the initial concept value at iteration  $t$ .  $A_j^{(t)}$  is the concept value at iteration  $t$ .  $(\mu_{ij}(w) - \pi_{ij}(w))$  is applied to reach the weight matrix.

**Step 6:** Determine concept values.

## 4 Case Study

A case study is conducted to analyze the SC risks in a manufacturing company. Due to privacy concerns and confidentiality issues, the company will be named XYZ. An evaluation model is proposed based on three main dimensions: production and inventory, customer service and delivery, and plant production. Risk factors concerning the main dimensions are determined with the help of decision-makers (DMs). A group of experts, including DMs, is constructed by considering their experience levels, backgrounds, academic careers, positions in the company where they work, and the knowledge levels related to the SC risks. The DMs determined the causality degrees of relationships (edges) between the risk factors using Table 2. Only the evaluations belong to a single DM (DM1) for the risk factors of Production & Inventory are given in Table 4 due to page limitations.

**Table 4.** Linguistic terms-based evaluation of PI risk factors

PI risk factors	C <sub>1</sub>	C <sub>2</sub>	C <sub>3</sub>	C <sub>4</sub>	C <sub>5</sub>	C <sub>6</sub>	C <sub>7</sub>	C <sub>8</sub>
C <sub>1</sub>	Z	PS	Z	Z	Z	Z	Z	Z
C <sub>2</sub>	Z	Z	Z	Z	PM	Z	Z	Z
C <sub>3</sub>	Z	NM	Z	Z	Z	NS	Z	Z
C <sub>4</sub>	Z	NW	Z	Z	Z	NW	Z	Z
C <sub>5</sub>	Z	Z	PS	Z	Z	Z	Z	Z
C <sub>6</sub>	Z	PW	Z	Z	Z	Z	Z	Z
C <sub>7</sub>	Z	Z	Z	Z	Z	PM	Z	Z
C <sub>8</sub>	Z	Z	Z	Z	Z	PVS	Z	Z

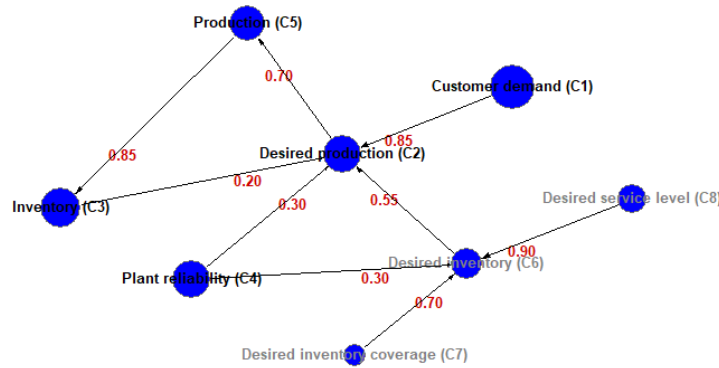


Visualized IFCM model of each main dimension with their sub-criteria are shown in Fig. 2, Fig. 3, and Fig. 4. Visualization of the IFCM model is performed by Pajek Software. The aggregated weight matrix is used for this. Following that, the concept (risk factor) values are calculated using Eq. (5), and they are given in Table 5 with their ranked orders.

**Table 5.** Concept values of supply chain risks and their ranked order

Production & Inventory		Customer Service & Delivery			Plant Production				
C <sub>2</sub>	0.44576	C <sub>4</sub>	0.43776	C <sub>7</sub>	0.42849	C <sub>15</sub>	0.41548	C <sub>9</sub>	0.40593
C <sub>6</sub>	0.44574	C <sub>11</sub>	0.43364	C <sub>5</sub>	0.42696	C <sub>8</sub>	0.41406	C <sub>14</sub>	0.40591
C <sub>1</sub>	0.44472	C <sub>3</sub>	0.43154	C <sub>2</sub>	0.42637	C <sub>2</sub>	0.40926	C <sub>5</sub>	0.40589
C <sub>4</sub>	0.44472	C <sub>6</sub>	0.43055			C <sub>6</sub>	0.40926	C <sub>10</sub>	0.40588
C <sub>7</sub>	0.44472	C <sub>10</sub>	0.43004			C <sub>11</sub>	0.40926	C <sub>12</sub>	0.40588
C <sub>8</sub>	0.44472	C <sub>8</sub>	0.43003			C <sub>13</sub>	0.40926	C <sub>16</sub>	0.40588
C <sub>5</sub>	0.44257	C <sub>1</sub>	0.42954			C <sub>4</sub>	0.40878	C <sub>1</sub>	0.40393
C <sub>3</sub>	0.44099	C <sub>9</sub>	0.42850			C <sub>3</sub>	0.40878	C <sub>7</sub>	0.40300

The concept values in Table 5 show that the most critical risk factors for production and inventory are the desired inventory, desired production, and customer demand. Furthermore, when Fig 2 is examined, it is seen that high customer demand increases the desired production. This triggers production, and consequently, the inventory is influenced. At the same time, desired service level, desired inventory coverage, and plant reliability positively influence desired inventory. If the desired inventory high, then the desired production is increased.



**Fig. 2.** IFCM model of *production & inventory* risks

As Table 5 states, inventory, demand backlog, and order fulfillment risk factors have greater importance in customer service and delivery risks. When Fig 3 is examined, it is seen that inventory influences inventory carrying cost and order fulfillment. At the same time, if the order fulfillment level is high, then customer satisfaction is high. Customer satisfaction triggers customer demand, and it causes a demand backlog. Accordingly, the desired shipment will be influenced. On the other hand, high product prices

will affect customer satisfaction. However, the product price is determined based on immediate shipment, inventory, inventory carrying cost, and unit shipment cost, which is also influenced by the immediate shipment.

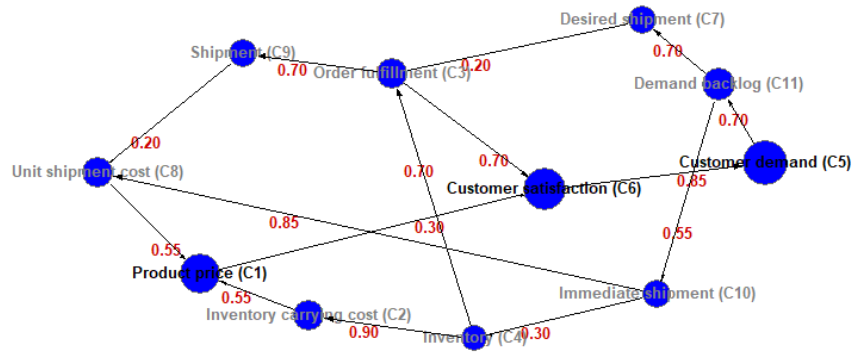


Fig. 3. IFCM model of *customer service & delivery risks*

Finally, the obtained results given in Table 5 shows that customer satisfaction, downtime, and desired production are the most critical factors in plant production risks. Furthermore, Fig 4 proves that product variety, product price, and product defects significant for customer satisfaction. But the variety of the production increases the setup time, and that increases the manufacturing lead time. The increase in the manufacturing lead time directly increases the unit production cost, and the increased unit production cost increases the price of the product. But the increased product price may influence customer satisfaction negatively.

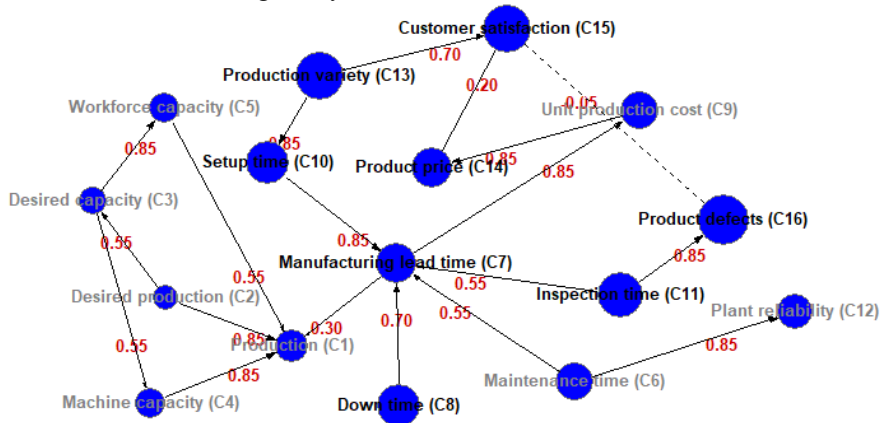


Fig. 4. IFCM model of *plant production risks*.

Manufacturing companies should focus on these risk factors in their SCRM processes. Furthermore, when the IFCM models are examined, it is seen that the sub-models have common criteria such as *desired production, plant reliability, production, inventory,*

*and customer satisfaction.* Since these risk factors connected these three subsystems as both influencing and influenced factors, it is possible to propose a general model for supply chain risks.

## 5 Conclusion and Perspectives

SCs are complex network-like structures with many components. These complex structures contain many risk factors. For managing these structures, companies need to focus on risk factors for their sustainability. Plus, profitability and determination of strategies concerning risks are also crucial for SCM. In this study, a model is proposed for the analysis of supply chain risk factors. A case study is conducted to validate the proposed model and risk factors in a manufacturing company in Turkey. IFCM approach is utilized for the analyzing process. The study reveals the importance of the risk factors for SCs, and the applied IFCM approach is helpful for such problems.

The proposed model can be developed by simultaneously analyzing all sub-criteria of the proposed to see the structure of the whole SC risk system. Interval-valued IF (IVIF) sets can be used to obtain more accurate and sensitive results. Furthermore, sensitivity and scenario analysis can be performed for future studies, and also the results can be compared.

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