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Original Research

A Model for Designing and Evaluating LARG-Based Supply Chain Using Axiomatic Design and the Best-Worst Method in a Hesitant Fuzzy Environment

Abedin Eftekhari and Gholamreza Jamali[1]
Department of Industrial Management, Persian Gulf University, Bushehr, Iran

Ali Naghi Mosleh Shirazi
Department of Management, Shiraz University, Shiraz, Iran

Abstract

There have been various approaches to the supply chain such as lean, agile, robustness, sustainability, resilient, and green that each one focuses on supply chain from specific aspect. One of the new approaches to the supply chain is an integration of Lean, Agile, Resilient, and Green (LARG) that benefiting from the advantages of different approaches and avoiding their disadvantages. The present study proposes a model to design and evaluate LARG-based supply chain in Iran automotive industry using the concept of Axiomatic Design (AD) in a Hesitant Fuzzy (HF) environment. The study process consisted of two stages: designing stage and evaluating stage. In the first stage, the Functional Requirements (FR) and chain Design Parameters (DP) identified in the LARG supply chain based on the Delphi technique and literature review. Based on independence axiom, it should be considered that whether the satisfaction of one FR by the related DPs affects the quality of the other FR or not, which is examined based on the design matrix. In the second stage an integration of information axiom, the Best-Worst Method (BWM), and hesitant fuzzy logic was used to evaluate four supply chains in Iran automotive industry. The weight of supply chain criteria, the utility rate of desired supply chain criteria, and the current status for each supply chain criteria identified in this stage. The results indicated that the excellent LARG supply chain was consisted of 13 indicators. The model also revealed that the excellent supply chain was contained less information axiom and complexity.

Keywords: Axiomatic Design, Best-Worst Method, Hesitant Fuzzy, LARG Supply Chain.

[1] *Corresponding Author's Email: gjamali@pgu.ac.ir*

Introductıon

The philosophy of supply chain management is to increase the cooperation and improve the communication between the internal sections of organizations, as well as the companies and organizations as the chain loops. Horvath (2001) argues the inconsistency and lack of integration are considered as one of the main reasons for the decreased supply chain performance, especially for the core supply chain companies. Supply chain contains different approaches, each of which has its own advantages and disadvantages. A supply chain needs to design, the lack of which increases the cost of supply chain due to the lack of considering the stakeholders' interests and environmental conditions, leading to the loss of coordination along the chain, and reduction of the competitiveness of the supply chain against the other chains. On the other hand, the level of relationship in the supply chain and its components is increasing and becoming more complex. Also, According to Daneshvar Kakhki and Hosseini (2014) the adaptation of the ability of organizations existing in the supply chain to the environment plays a key role in their survival. Espadinha-Cruz et al. (2011) believe there are several approaches to the supply chain design. The current supply chain strategies include Lean, Agile, Resilient, and Green (LARG) contributing supply chain to improve its performance and increase its efficiency and effectiveness based on the existing methods. Each strategy takes the different approach and method for better supply chain. For example, the lean concerns on the product design and production to minimize waste and maximize the profits by reducing the costs. Further, the proponents of the agile strategy generally consider more and faster responsiveness to the customers and profit maximization by providing the desired product accurately. The resilient strategy, referring to the impact of external factors on the chain, considers the chain stability in the critical situations. Finally, the main concern in the green supply chain is to reduce the impact of the environmental activities of chain on the environment. Accordingly, Ghasemiyeh et al. (2015) studies showed a supply chain with an integrated approach should be designed to avoid the disadvantages of each approach and help companies in this regard. The principled and systematic design of the supply chain and the simultaneous combination of the available methods and activities in these four strategies are known as the LARG supply chain, which generally integrates the objectives and increases the competitiveness of the supply chain.

According to Carvalho et al. (2011) a LARG supply chain is a complex and multidimensional system in which lean, agile, resilient, and green strategies are integrated and multiple entities and stakeholders are involved. It should be designed very carefully and delicately since ineffective design imposes a lot of costs to the supply chain. Therefore, there should be a systematic view in the design. Accordingly, the present study used the Axiomatic Design (AD) technique for the LARG supply chain design. Sheikh (2007) argues that axiomatic design technique is suitable for multidimensional and complex systems and the design in this technique is based on the requirements of the stakeholders. Another important issue in the present study is the existence of uncertainty in the LARG supply chain. Torra (2010) developed a fuzzy approach named Hesitant Fuzzy (HF), trying to model doubt and uncertainty at the same time. The present study aimed to design LARG supply chain based on the hesitant fuzzy algorithm and axiomatic design technique.

Literature Review

A large number of studies have been conducted on the LARG supply chain. Carvalho and Cruz-Machado (2011) examined the integration of the LARG paradigms in the supply chain management (LARG-SCM). They found that the lean, agile, resilient, and green patterns have a general and unit objective of achieving customer satisfaction by the lowest cost each approach of the supply chain has its own advantages and disadvantages. Benefiting from the advantages of these approaches and planning to eliminate their disadvantages increase the value creation potential in the supply chain (Carvalho and Cruz-Machado 2011).

Stavrulaki et al. (2010) reported optimizing organizational processes regardless of the external companies, especially suppliers and customers, seems futile and the organizations working together to achieve common objectives perform better. Accordingly, the concept of supply chain was created. The LARG supply chain management tries to integrate the lean, agile, resilient, and green approaches in the supply chain management space to benefit from their advantages and cover their shortcomings simultaneously.

Azevedo et al. (2011a) proposed a conceptual model for improving the operational, economic, and environmental performance of supply chains based on the methods and activities of lean, agile, resilient, and green, leading to the understanding of the integrated LARG supply chain deeply. Carvalho et al. (2012) stated that the supply chain design mainly aimed to minimize the cost or optimize the services in the past and emphasized the characteristics of resilient in the supply chain. They introduced the combination of the agile and resilient to improve the market share and strengthen the market leadership capacity since the characteristics of the agile and resilient influence the chain performance and contribute to the supply chain to be more competitive in terms of time, quality, and the level of customer service. Further, they suggested that the LARG combined approach should be considered experimentally as an appropriate strategy for improving the supply chain performance.

Maleki and Cruz-Machado (2013) proposed a generic integration of lean, agile, resilient, and green practices with respect to the customer values in the automotive industry, using the analysis of business networks. They classified the LARG methods based on the production/assembly/logistics methods and then, generalized to the customer values, including quality, cost, and paying attention to the environment, knowledge, customization, and time.

Mohammad Nejad and Safaei Qadikani (2016) identified the criteria for selecting suppliers in the LARG supply chain in the food and dairy industries and ranked them using fuzzy network analysis. Further, Cabrita et al. (2016) presented an integrated approach of lean, agile, resilient, and green approaches, called LARG, in response to the increasing external changes in organizations and specified why and how we should communicate between these paradigms in this model of businesses and identified the factors. Ruiz-Benitez et al. (2018) examined the relationship between the supply chain management of lean, agile, resilient, and green and performance evaluation in the aerospace sector by combining the Importance-Performance Analysis (IPA) technique and Interpretive Structural Modeling (ISM) approach.

Jamali and Karimi Asl (2018a) determined the competitive positioning for LARG supply chain using SWOT technique and importance-performance analysis and examined their strategic requirements in the cement industry. Jamali and Karimi Asl (2018b) identified the criteria of each LARG supply chain strategy and evaluated LARG supply chain strategies in the cement industry using multi-criteria decision-making technique and gap analysis. Lopez and Ruiz-Benitez (2020) proposed a combination of lean, resilient, and green strategies in the supply chain decisions of the success key in moving towards sustainability. They reported that the structural-interpretive model is an appropriate tool for the chain management in the sustainability programs at every level of the supply chain.

Udokporo et al. (2020) indicated the impact of lean, agile, and green strategies on business competitiveness, entitled LAG, and evaluated the relationship between LAG and the competition between the businesses. The delay, cost, and sustainability in the business improve by considering this relationship. Mohammed (2020) raised the issue of selecting supplier by combining the resilient and green strategies, entitled green resilient, and introduced the indicators, which the green resilient suppliers should have in the supply chain.

However, a large number of studies have been conducted on using axiomatic technique in designing organizational issues. Heo and Lee (2007) used the principle of the independence of axiomatic design technique in designing cooling systems in the nuclear power plant. Further, Sheikh (2007) set his strategy and planning to attract and retain customers using the axiomatic design technique of car manufacturers and recognized the most important factors influencing the customers' decision to choose a car and compare their situation with competitors.

Ferreira et al. (2013) used axiomatic design technique to design a high-precision mold in a casting project to produce mostly plastic parts. Espadinha-Cruz et al. (2019) used a combination of axiomatic design technique and benchmarking to fully understand what the customer wants in order to design the customer's needs.

Güler et al. (2019) designed the digital transformation strategies to develop new businesses by combining the axiomatic design technique and fuzzy hierarchical analysis.

Goo et al. (2019) designed the reliability criteria in the maintenance of the gas company using the independence axiom of axiomatic design technique and FMECA. In addition, Padala and Maheswari (2019) presented an axiomatic design framework for changeability in designing for metro and hotel executive projects and identified necessary and unnecessary changes. Xingli and Liao (2020) used fuzzy axiomatic design technique for financing in the supply chain by considering credit risk management.

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Table 1. Summary of the studies conducted in the field of LARG supply chain

Author(s)	Objective	Method	Result
(Carvalho et al., 2011)	Integrating supply chain approaches	Interpretive-analytical	Increase customer satisfaction with the lowest cost
(Azevedo et al. 2011b)	Presenting a conceptual model with an emphasis on lean, resilient, and green strategies	Presenting a conceptual model	Understanding of the LARG supply chain deeply
(Carvalho et al., 2012)	Resilient supply chain design	Quantitative technique	Identifying and focusing on the features of resilient
(Maleki and Cruz-Machado, 2013)	Presenting a general approach for integrating LARG strategies	Interpretive-analytical	Identifying customer values based on the LARG strategies
(Shoushtari, 2013)	Supply chain design	Quantitative models of score and VSM	Increasing the efficiency and performance of the supply chain
(Mohammad Nejad and Safaei Qadikani, 2016)	Identifying the criteria and selecting a supplier in the LARG supply chain	Fuzzy network analysis	Ranking supplier in the LARG supply chain
(Cabrita et al., 2016)	Providing LARG approach in response to the external changes of the organization	Presenting an approach	Identifying the factors and the relationship between LARG paradigms
(Lopez and Ruiz-Benitez, 2020)	The relationship among lean, resilient, and green supply chain management and performance evaluation	Integrating the Importance-Performance Analysis (IPA) and Interpretive Structural Modeling (ISM) techniques	Improving the performance of the organization
(Jamali and Karimi Asl, 2018a)	Determining the competitive position of the LARG supply chain	SWOT technique	Determining the position of each LARG strategy in the SWOT table and the importance-

Author(s)	Objective	Method	Result
			performance analysis of each strategy
(Jamali and Karimi Asl, 2018b)	Evaluating LARG supply chain strategies	Gap analysis technique	Identifying the criteria of each strategy and prioritizing
(Lopez and Ruiz-Benitez, 2020)	Creating organizational sustainability with a combination of lean, resilient, and green	Interpretive-analytical	Creating resilient organizations if lean, green, and resilient strategies are integrated
(Udokporo et al., 2020)	The effect of lean, agile, and green on the competition of businesses, entitled LAG	Interpretive-analytical	Improving the status of delay, cost, and sustainability in the business
(Amjad et al., 2020)	Proposing an approach, entitled Gresilient	Presenting an approach	Selecting the green resilient suppliers in the supply chain

Based on the above literature, the following conclusions are made.

- Combining different approaches leads to the creation of an integrated approach such as LARG approach, which is accepted and pursued by some researchers.

- In LARG approach, the supply chain design is considered less, and the main focus has been on the advantages and development of LARG supply chain strategies. Further, quantitative and mathematical modeling approach is examined in a few studies conducted on the LARG supply chain design.

- The appropriate methods for designing a concept such as the axiomatic design technique, which indicated its capabilities in designing many subjects, are not used in supply chain design, especially LARG supply chain.

- Despite many advances in the field of modeling in the conditions of uncertainty, the capabilities of modeling in fuzzy spaces such as hesitant fuzzy are evaluated in a few studies conducted on the LARG supply chain design.

Thus, by identifying the existing research gaps, the present study sought a method to design the LARG supply chain qualitatively and conceptually by using the axiomatic design technique in the hesitant fuzzy space.

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Research Methodology

The present study consisted of two general stages. In the first stage, the LARG supply chain was designed qualitatively and in the second stage, the supply chain was evaluated quantitatively. Therefore, this research is placed in the category of the consecutive hybrid research (qualitative-quantitative). Fig.1 displays general process of the research.

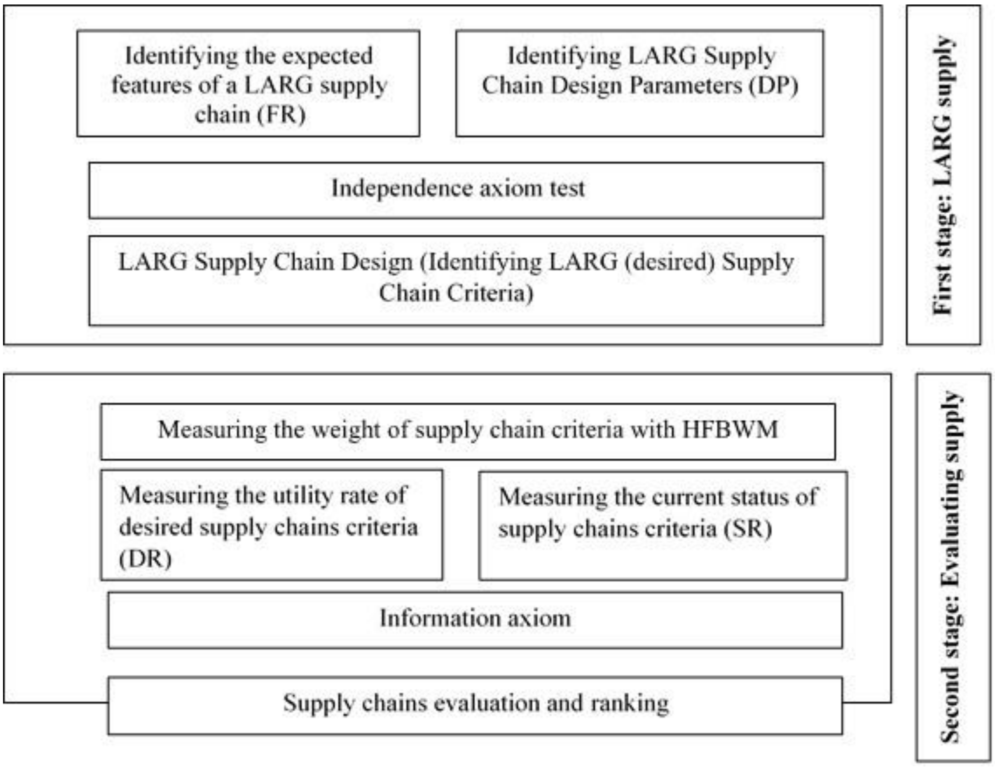

Figure 1: Research process

LARG supply chain design (First stage)

In the first stage we used the axiomatic design technique to design the LARG supply chain. Suh (1999) introduced this technique for the first time (Espadinha-Cruz et al., 2019). He argues in axiom-oriented design, the problem is defined in the form of Functional Requirements (FR), originating from the needs of the customer (user or beneficiary). Then, the tools and mechanisms are specified to meet the functional requirements, called Design Parameters (DP). In this technique, two axioms conclude independence axiom and information axiom should be considered.

In the present study, the independence axiom was considered in the design stage and information axiom in the evaluation stage.

In order to observe the independence axiom in designing, it should be considered that whether the satisfaction of one FR by the related DPs affects the quality of the other FR or not, which is examined based on the design matrix. Accordingly, the following steps are taken:

Identifying the expected features of the LARG supply chain (FR)

IN this step, the related requirements of a LARG supply chain were determined. For this purpose, the opinions of academic experts, managers of the different sectors of the supply chain, background of the study, and Delphi technique were used.

Identifying the design parameters (DP) of the LARG supply chain

The requirements for meeting the related needs of a LARG supply chain in the automotive industry were identified using Delphi technique. The functional requirements (FR) and the design parameters (DP) were hierarchically broken and interconnected as zigzags.

Independence axiom test

Based on what was mentioned about the independence axiom, the independence status of DP and FR was examined in this step to ensure their independency.

Evaluating of supply chains (Second stage)

This stage is created based on the combination of the information axiom of the axiomatic design, the Best-Worst Method, and hesitant fuzzy logic. The information axiom is based on the principle that the success of a project is directly related to the probability of achieving FRs. The probability of achieving FRs reduces by increasing the amount of information required to meet FRs. Accordingly, the appropriate plan contains the minimal information content. The system area, design area, and common area were calculated to compute the amount of information load. Fig. 2 displays system area, design area, and common area.

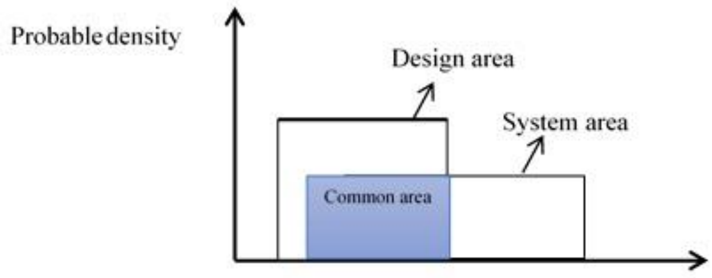

Figure 2: System area, design area, and common area

The design area refers to the expected ability, the system area indicates the current ability of the system, and the common area represents the amount of commonality between the system area and design area.

Moaddi and Sheikh (2015) explained if a system is chosen in such a way that its design area (expected ability) covers the system area (current ability), the system area is a subset of the design area and the design meets all expected demands to achieve FRs. In such a case, the probability of the project success in achieving its objective is equal to one, and if it does not cover the design area, this probability is equal to zero. The less effort is required to carry out activities and achieve objectives when the common area is higher.

Simply the probability of success in FR satisfaction is expressed as the reverse logarithm of the probability of success.

$$I = \log_2 (\frac{1}{P}) \quad (1)$$

$$P = (\text{System area / common area}) \quad (2)$$

$$I = \log_2 (\text{Common area / system area}) \quad (3)$$

Where P indicates the probability of success and I represent the system information load rate.

The Best-Worst Method is an alternative to the AHP method, proposed by Rezaei (2016) which is used to determine the weight of supply chain criteria. Therefore, the steps of the second stage are as follows (Celik et al. 2009):

Determining weight of the supply chain criteria

Mi and Liao (2019) proposed an integration of Hesitant Fuzzy and Best-Worst Method (HFBWM) that was used to determine the weight of the LARG supply chain criteria due to the uncertainty in the decision-making space. The steps of this method are as follows:

- Determining the most and least important criterion

- Identifying the preference of the most important criterion over the rest of the criteria and the preference of the rest of the criteria over the least important one.

- Specifying the amount of score

The score of each answer is determined through Eq. 4.

$$s(h) = \frac{1}{\# h} \sum_{\gamma \in h} h \quad (4)$$

Where *s (h)* indicates the amount of score $\# h$ represents the number of elements of the hesitant fuzzy set, and h displays the degree of memberships of the hesitant fuzzy set. It should be noted that $h_{BB} = h_{WW} = \{0.5\}$.

Therefore, the preference rate of the most important criterion compared to the other criteria and the preference of other criteria compared to the least important one are as follows:

$$\begin{aligned} s(HFBO) &= (s(h_{B1}), s(h_{B2}), \dots s(h_{Bj}), \dots, s(h_{Bn})) \\ s(HFOW) &= (s(h_{1W}), s(h_{2W}), \dots s(h_{jW}), \dots, s(h_{nW}))^T \end{aligned} \quad (5)$$

Calculating of the weights

The weight of the indicators is calculated using the optimization Eq. 6.

$$\begin{aligned} &\min \ \psi_S \\ &s.t.: \left|\omega_B - (\omega_B + \omega_j) \times s(h_{Bj})\right| \le \psi_S \\ &\left|\omega_j - (\omega_j + \omega_W) \times s(h_{jW})\right| \le \psi_S \\ &\sum_{j=1}^{n} \omega_j = 1, \omega_j \ge 0 \end{aligned} \quad (6)$$

Measuring the utility rate of desired supply chain criteria (DR)

The utility rate of each of the LARG supply chain criteria should be specified in this step. These utility rates are considered as DRs. For this purpose, Table 2 is used in the hesitant fuzzy space.

Table 2. Conversion of linguistic terms

Linguistic variables	Triangular fuzzy numbers (TFNs)
Very Poor	(0%, 0%, 20%)
Poor	(0%, 20%, 40%)
Fair	(20%, 40%, 60%)
Good	(40%, 60%, 80%)
Very Good	(60%, 80%, 100%)
Excellent	(80%, 100%, 100%)

Measuring the current status of supply chains criteria (SR)

At this step, the current status of the supply chains is determined based on the criteria. The current status is the same SR.

The aggregation operator (GHFWA) is used to combine the respondents' opinions.

$$GHFWA_{\lambda}(h_1, \ldots, h_2) = (\oplus_{j=1}^{n}(w_j h_j)) = \bigcup_{\gamma_1 \in h_1, \ldots, \gamma_n \in h_n} \left\{ \left(1 - \prod_{j=1}^{n} 1 - \gamma_j)^{w_t} \right) \right\} \quad (7)$$

Where γ displays the elements of the hesitant fuzzy set and w_j indicates the weight of each expert.

Information axiom test

Based on the information axiom concept, the common area is first determined and then, the amount of information axiom (I) is calculated with respect to the utility rate of the LARG supply chain criteria (DR) and the current status of LARG supply chain criteria (SR).

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$$I = \log_2 (\text{System area} / \text{Common area}) \qquad (8)$$

Given the the information content of each dimension and the weight of the indicators, the information content of each supply chain is obtained using Eq. 9.

$$I_{ij} = \begin{cases} \left[\log_2 \dfrac{1}{p_{ij}}\right]^{\frac{1}{W_j}}, & 0 \le I_{ij} < 1 \\ \left[\log_2 \dfrac{1}{p_{ij}}\right]^{W_J}, & I_{ij} > 1 \\ W_j, & I_{ij} = 1 \end{cases} \qquad (9)$$

After the final calculation of Ii using the Eq.9, $\prod I_i$ should be calculated in each option.

Supply chains evaluation and ranking

The supply chains are ranked based on the lower information load or less complexity in this step.

Results

The research results are presented based on the research stages, respectively.

LARG supply chain design (First stage)

Identifying the expected features of the LARG supply chain (FR)

The related requirements from the LARG supply chain in the automotive industry create a powerful supply chain as a general objective, which is considered as FR0, which is possible when the LARG supply chains strategies such as green strategy (FR1G), lean strategy (FR1L), agile strategy (FR1A), and resilient strategy (FR1R) in the lower levels of empowerment are considered as more detailed objectives in the automotive supply chain. Each of the FRs is decomposed into lower levels using the Delphi technique and experts' opinions (Fig. 3).

Identifying the design parameters (DP) of the LARG supply chain

All DPs are identified based on the Delphi technique and background review. The LARG supply chain design is considered as DP0 to create a powerful supply chain at zero level (FR0). Further, the lower levels of DPs are considered the same as in Fig. 3. The important point is the zigzag structure of the relationship between DPs and FRs (Fig. 3).

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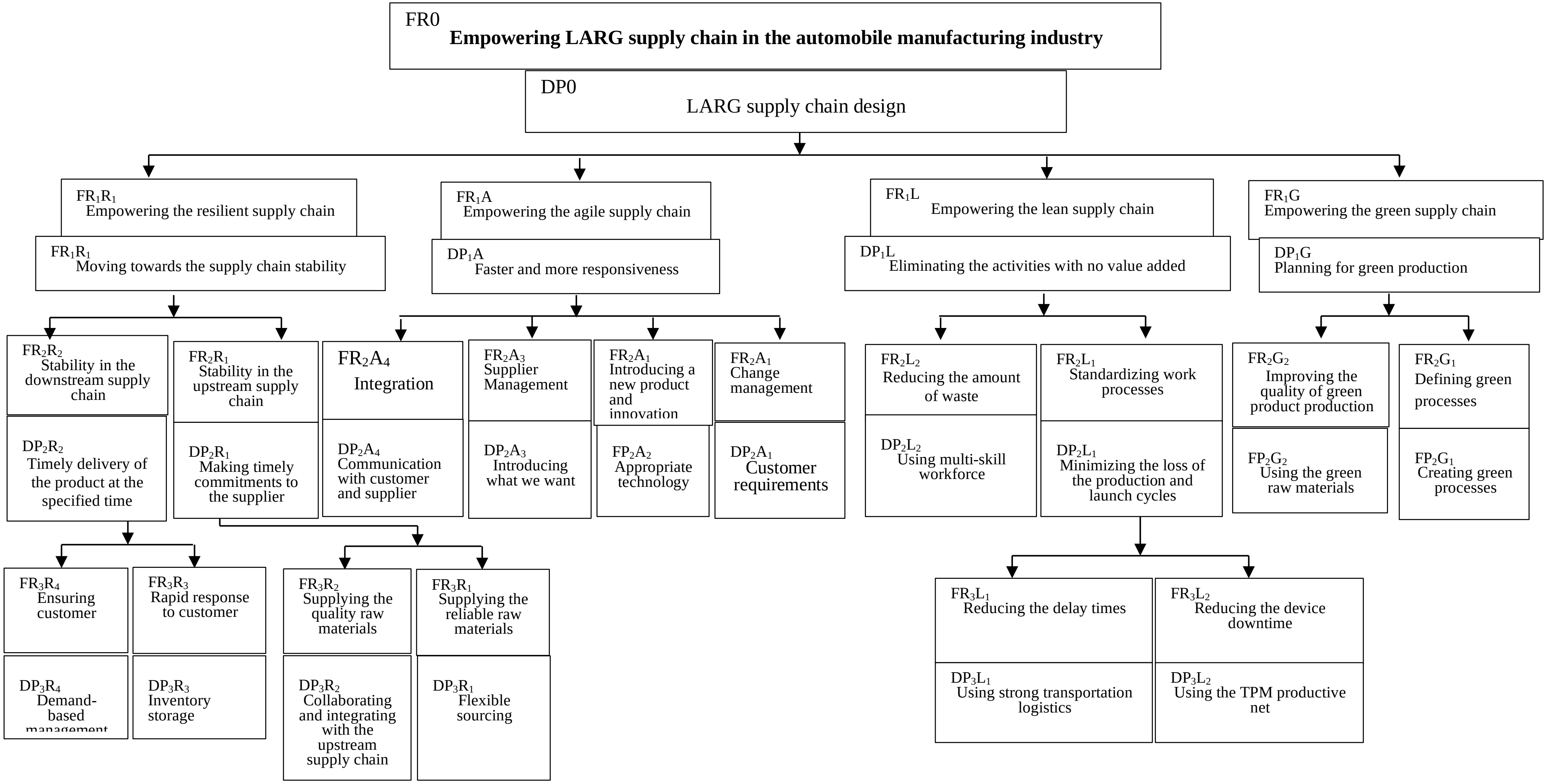

Fig.3. LARG supply chain design with the independence axiom

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The independence axiom test

In this step, it should be examined and analyzed that each of the DPs in the lower level is only related to its functional requirements (FRs) without any effect on the other objectives. The design matrix is used for this purpose (Fig. 4), which is formed based on the analysis of the expert's opinions.

$$\begin{bmatrix} FR2G1 \\ FR2G2 \\ FR2L2 \\ FR3L1 \\ FR3L2 \\ FR2A1 \\ FR2A2 \\ FR2A3 \\ FR2A4 \\ FR3R1 \\ FR3R2 \\ FR3R3 \\ FR3R4 \end{bmatrix} \equiv \begin{bmatrix} XOOOOOOOOOOOO \\ OXOOOOOOOOOOO \\ OOXOXOOOOOOOO \\ OOOXOOOOOOOOO \\ OOOOXOOOOOOOO \\ OOOOOXOXOOOOO \\ OOOOOXXXOOOOO \\ OOOOOOOXOXXOO \\ OOOOOOOOXOXOO \\ OXOOOOOOXXOOO \\ OOOOOOOOXOXOO \\ OOOOXXXXXOOXO \\ OOOXOOXXXOOXX \end{bmatrix} \begin{bmatrix} DP2G1 \\ DP2G2 \\ DP2L2 \\ DP3L1 \\ DP3L2 \\ DP2A_1 \\ DP2A_2 \\ DP2A_3 \\ DP2A_4 \\ DP3R1 \\ DP3R2 \\ DP3R3 \\ DP3R4 \end{bmatrix}$$

Fig.4. design matrix

In Fig. 4, *O* indicates the lack of influence and *X* demonstrates the relationship. The design matrix is independent when the only main diameter is *X*, namely each DP is only related to one FR. The design matrix is semi-independent in the present study. Some DPs affect more than one FR and an example of them is analyzed in the following.

FR2G1 = XDP2G1

In fact, the definition of green processes (FR2G1) is only achieved through the creation of green processes (DP2G1), indicating the complete independence of FR2G1 from other DPs.

FR3R4= (XDP3L1) + (XDP2A2) + (XDP2A3) + (XDP2A4) + (XDP3R3) + (XDP3R4)

In other words, customer assurance (FR3R4) is not achieved only through the demand-based management (DP3R4). However, the criteria such as the use of strong transportation logistics (DP3L1), appropriate technology (DP2A2), control and supervision (DP2A3), communication with the customer and supplier (DP2A4), and inventory and strategic surplus storage (DP3R3) affect the quality of achieving the customer assurance.

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As the matrix indicated, the proposed design is semi-independent. The first axiom, the independence axiom, is accepted and the design parameters of the supply chain at the lowest level are introduced as the LARG supply chain criteria in the automotive industry (Fig. 5).

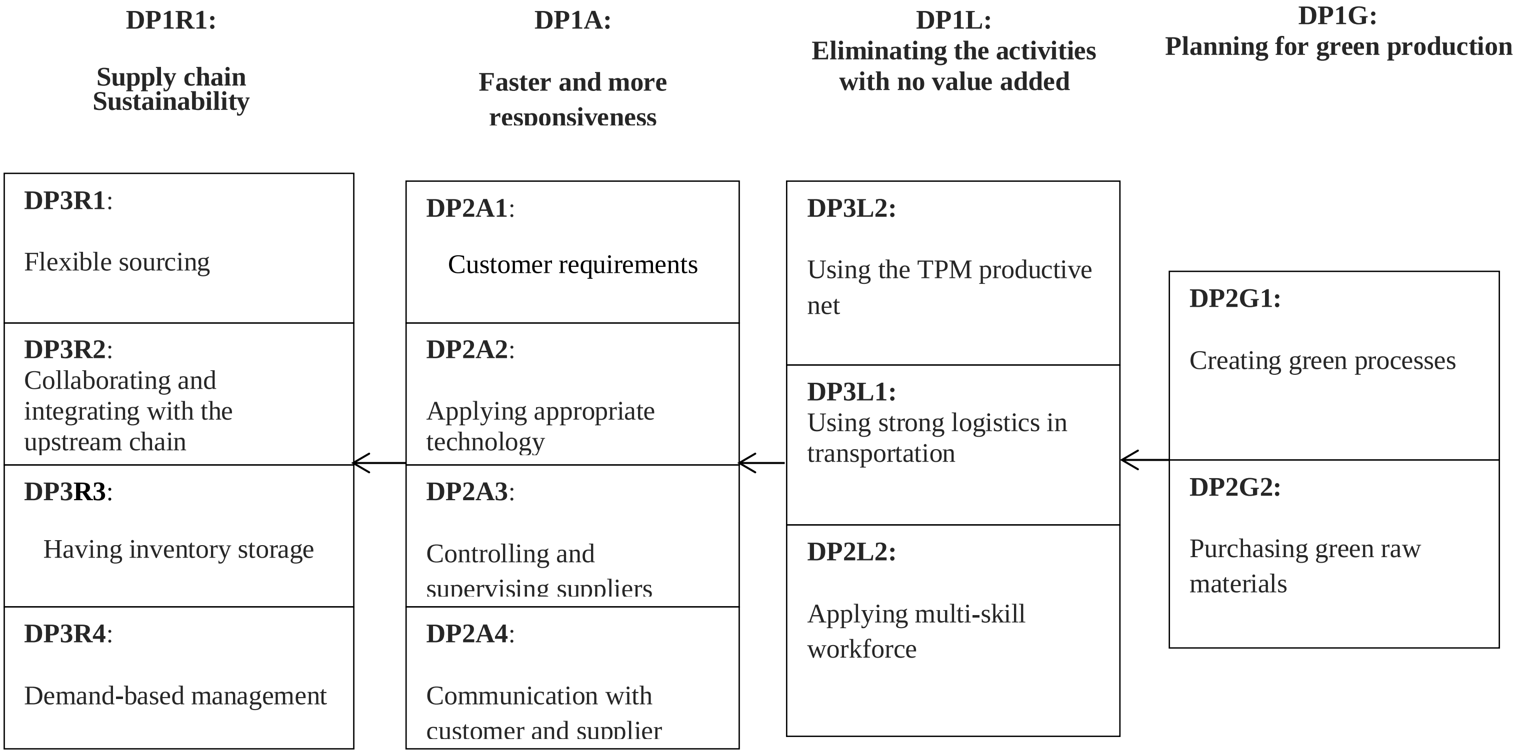

Fig.5. LARG (desired) supply chain criteria in the automotive industry

Evaluating the supply chains (Second stage)

Determining the weight of the supply chain criteria

At this step, the dimensions and criteria were separately weighted based on the hesitant fuzzy Best-Worst Method. For example, Tables 3 and 4 indicate the weight determination of the dimensions based on the opinions of the first expert.

Table 3. Selecting dimension with the most importance

Dimension	Lean/DP1L	Agile/DP1A	Resilient/DP1R	Green/DP1G
Agile/DP1A	FI,WI	EI	FI,VI	VI
Hesitant Numbers	0.6, 07	0.5	0.7, 0.8	0.8
S(HFBO)	0.65	0.5	0.75	0.8

Table 4. Selecting dimension with the least importance

Dimension	Green/DP1G	Hesitant Numbers	*S(HFOW)*
lean/DP1L	FI,VI	0.7, 0.8	0.75
Agile/DP1A	VI	0.8	0.8
Resilient/DP1R	WI	0.6	0.6
Green/DP1G	EI	0.5	0.5

The linguistic terms were converted into the fuzzy numbers (Table 5).

Table 5. Membership degree of the linguistic terms

Linguistic terms	Symbol	Membership Degree
Equal importance	EI	0.5
A little excellent	WI	0.6
Excellent	FI	0.7
Very excellent	VI	0.8
Very excellent	EI	0.9

Now, the following optimization model should be solved to calculate the weights.

$$\begin{aligned} &\min : \varphi \\ &|\omega_2 - (\omega_2 + \omega_1)0.65| \leq \varphi \\ &|\omega_2 - (\omega_2 + \omega_3)0.75| \leq \varphi \\ &|\omega_2 - (\omega_2 + \omega_4)0.8| \leq \varphi \\ &|\omega_1 - (\omega_1 + \omega_4)0.75| \leq \varphi \\ &|\omega_3 - (\omega_2 + \omega_4)0.6| \leq \varphi \\ &\omega_1 + \omega_2 + \omega_3 + \omega_4 = 1 \\ &\omega_1, \omega_2, \omega_3, \omega_4 \geq 0 \end{aligned} \tag{10}$$

For example Table 6 indicates the result of solving the model to obtain the weights based on the opinion of the first expert.

Table 6. The weights based on the opinion of the first expert

Wlean(DP1L)	WAgile(DP1A)	WResilient(DP1R)	WGreen(DP1G)	MIN FI
0.27	0.46	0.17	0.10	0.01

Table 7 shows the same procedure that was performed for five experts. It is clear that final weight of dimensions depends on the average of experts' opinions.

Table 7. Final weight based on the experts' opinions

Expert	Wlean (DP1L)	Wagile (DP1A)	Wresilient (DP1R)	Wgreen (DP1G)	MIN FI
1	0.27	0.46	0.17	0.10	0.01
2	0.22	0.27	0.39	0.11	0.04
3	0.14	0.38	0.30	0.18	0.10
4	0.23	0.23	0.46	0.09	0.02
5	0.08	0.43	0.39	0.10	0.02
Final	0.19	0.35	0.34	0.12	0.04

The same procedure was performed to determine the weight of the criteria of each dimension. Fig. 5 displays desired supply chain (LARG) criteria and Table 8 displays final results.

Table 8. Final weight of the criteria in each dimension

Dimension	Weight of each dimension	Final weight
Green/DP1G	0.12	
DP2G1	0.37	0.04
DP2G2	0.63	0.07
Lean/DP1L	0.34	
DP2L2	0.20	0.07
DP3L1	0.44	0.15
DP3L2	0.36	0.12
Agile/DP1A	0.35	
DP2A1	0.26	0.09
DP2A2	0.43	0.15
DP2A3	0.19	0.08
DP2A4	0.12	0.05
Resilient/DP1R	0.19	
DP3R1	0.21	0.05
DP3R2	0.22	0.06
DP3R3	0.18	0.04
DP3R4	0.40	0.07

Measuring the utility rate of desired supply chain criteria (DR)

The opinions of decision makers on the required minimum utility of 13 criteria in the automotive industry were collected (Table 9).

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Table 9. Utility rate of desired supply chain criteria (DR)

DP2 G1	DP2G2	DP3L2	DP3L1	DP2L2	DP2A1	DP2A2	DP2A3	DP2A4	DP3R1	DP3R2	DP3R3	DP3R4
At Least Good	At Least very Good	At Least Very Fair	At Least Very Good	At Least Fair	At Least Good	At Least Good	At Least Very Good	At Least Poor	At Least Good	At Least Very Good	At Least Good	At Least Poor

Measuring the current status of the supply chain criteria (SR)

Four supply chains in the automotive industry were evaluated in this step. For this purpose, the opinions of seven decision makers on the current status of the criteria in four supply chains were collected. Table10 demonstrates the first expert's opinion as an example.

Table 10. Opinion of the first expert as an example

Exp1	DP2 G1	DP2 G2	DP3 L2	DP3 L1	DP2 L2	DP2 A1	DP2 A2	DP2 A3	DP2 A4	DP3 R1	DP3 R2	DP3 R3	DP3 R4
SC1	VP,P	F,G	F,G	P,F	F,G	F,G	P,F	F,G	F,G	F,G	F,G	P,F	F,G
SC2	P,F	F,G	P,F	G,VG	P,F	VP,P	F,G	F,G	F,G	P,F	VG,EX	P,F	P,F
SC3	F,G	F,G	P,F	VP,P	F,G	F,G	F,G	G,VG	F,G	F,G	G,VG	G,VG	F,G
SC4	P,F	F,G	F,G	F,G	VG,EX	G,VG	P,F	VP,P	F,G	P,F	F,G	G,VG	G,VG

Then the opinions of the experts were collected and the System Range (SR) was obtained using the aggregation operator (Eq. 7).

Information axiom test

The score of the information axiom was computed by calculating the common area between the system area and design area (Fig. 6.).

For example, DP2G2 criterion in the SC1 chain is calculated as follows:

System Range for DP2G2 ⟶ Fair-Good

Design Range for DP2G2 ⟶ Very Good – Excellent

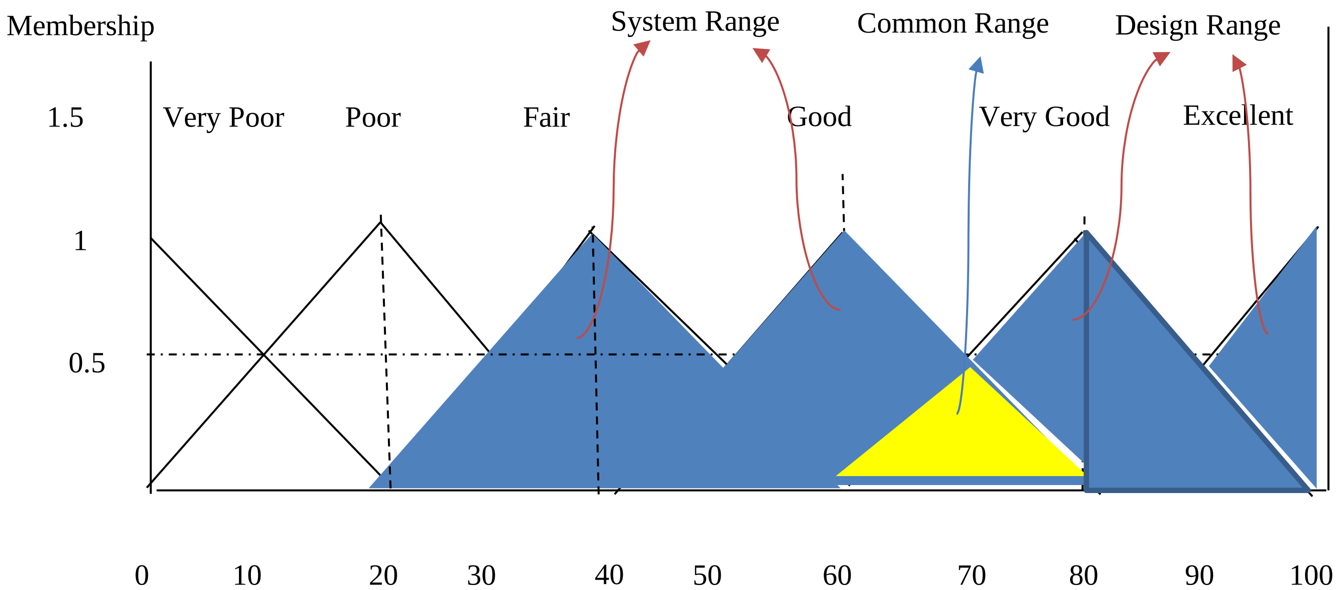

Fig.6. system range and design range for DP2G2

Therefore, the area level of the system area, common area, system area/common area, and the amount of the information axiom of each dimension were calculated for all criteria and for four supply chains based on the Eq. 3

The amount of information axiom obtained for each dimension was combined with the weight of that dimension (Table 8) and the amount of information axiom for each supply chain was calculated according to the Table 11.

Table 11. The amount of information axiom for each supply chain

SC1	SC2	SC3	SC4
1.663	1.663	1.651	1.590

Supply chains evaluation and ranking

The excellent supply chain contained less information axiom and less complexity. The supply chains were ranked from less to more bases on the amount of the information axiom. As indicated in Table 11, supply chain No.4 with an amount of 1,590 information axiom was introduced as the optimal supply chain.

Discussion and Conclusion

The present study aimed to design a LARG supply chain model in the automotive industry. The LARG supply chain is a new approach to the subject of the supply chain, which seeks to benefit from the advantages of the different approaches and avoid their disadvantages by integrating lean, agile, resilient, and green approaches. This research was conducted in two stages. In the first stage, a conceptual design was proposed for the LARG supply chain in the automotive industry using the independence axiom of

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axiomatic design. In the second stage, a method was suggested using the information axiom of this technique and its integration with the best -worst method in the hesitant fuzzy sets in order to evaluate the LARG supply chain. Accordingly, four automotive supply chains were evaluated.

Based on the results, the LARG supply chain consisted of 13 indicators. In this regard, the green raw materials should be purchased in the automotive industry and the nature-friendly processes should be used for the production in order to empower the green paradigm in the supply chain. For empowering the lean paradigm in the supply chain, productive maintenance in production should be on the agenda and strong transportation and multi-skill workforce should be used. Further, the agile supply chain is empowered through considering the customer requirements in the production, updating the technology, and transferring the customer’s requirement to the producer by suppliers and agents, communicating with the customer and supplier to increase customer responsiveness. Some criteria such as the flexible sourcing, cooperation and integration with the upstream supply chain, availability of appropriate precautionary reserve, demand-based management, lack of deficit, and excess inventory along the chain are necessary to achieve a sustainable supply chain.

The use of productive maintenance and repair is considered as a tool to empower the lean supply chain, which is consistent with the finding of Bortolotti et al. (2015), Jamali et al. (2017), and Espadinha-Cruz et al. (2011). The lean supply chain seeks to eliminate the activities with no value-added, which is in line with the study result of Benmousa et al. (2017) and Carvalho et al. (2011). Additionally, the responsiveness speed is known as a tool for the lean supply chain empowerment, which is consistent with the finding of et al. (2011a) and Jamali et al. (2017).The communication with customer is considered as another tool for the supply chain agility, which is in line with the result of Bortolotti et al. (2015). Furthermore, the demand-based management is known as a tool for supply chain resilient, which is in line with the findings of Carvalho et al. (2012). The purchase of green raw materials and the creation of green processes are recognized as important criteria to empower the green supply chain, while Benmousa et al. (2017) and Zhu, et al. (2008) identified the energy consumption and pollution control as the important tools to achieve the green supply chain.

Further, the results indicated that the most important criteria of the LARG supply chain include the use of strong logistics in transportation, appropriate technology, and multi-skill workforce and the least important criteria encompasses the use of inventory storage and the green process creation. In addition, among the main approaches of lean, agile, green and resilient, the agile approach is considered as the most important one and the green approach is known as the least important one, which is in line with the findings of Mohammad Nejad and Safaei Qadikani (2016).

The application of the hesitant fuzzy axiomatic design in the supply chain design and its integration with the hesitant fuzzy BWM are considered as the theoretical contribution of the present study. This integration makes the designed model have many capabilities compared to the existing models.

Evaluating the supply chain of other industries based on the proposed model and using other fuzzy sets such as type-2 fuzzy and intuitionistic fuzzy in the LARG supply chain design are recommended for further research.

Research Contribution

-In LARG approach, the supply chain design is considered less, and the main focus has been on the advantages and development of LARG supply chain strategies. Further, quantitative and mathematical modeling approach is examined in a few studies conducted on the LARG supply chain design.

-The appropriate methods for designing a concept such as the axiomatic design technique, which indicated its capabilities in designing many subjects, are not used in supply chain design, especially LARG supply chain.

-Used the independence axiom for LARG-Based Supply Chain Conceptual Design and an integration of the information axiom and the Best-Worst Method (BWM) was used to evaluation in a Hesitant Fuzzy (HF) environment due to the existing uncertainties.

- Combining different approaches leads to the creation of an integrated approach such as LARG approach, which is accepted and pursued by some researchers.

-Despite many advances in the field of modeling in the conditions of uncertainty, the capabilities of modeling in fuzzy spaces such as hesitant fuzzy are evaluated in a few studies conducted on the LARG supply chain design.

Thus, by identifying the existing research gaps, the present study sought a method to design the LARG supply chain qualitatively and conceptually by using the axiomatic design technique in the hesitant fuzzy space.

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