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Supply Chain Redesign: Strategic Decision Framework for Competitive Advantage

Morteza Abbasi[a*], Yoones Kermanshahian[b]

[a]*Department of Management Malek-Ashtar University, Tehran, Iran.*
[b]*Department of Management Mehr-Alborz Institute of Higher Education, Tehran, Iran.*

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ABSTRACT

This paper presents a framework to prioritize the supply chain strategies (SCS) according to all involved criteria, including objectives, process characteristics, product types, and environmental and demand conditions, to gain competitive advantages. This process has been done for the entire SC and upstream, downstream companies, and the focal companies of SC separately. Literature review and nominal group technique were used to identify customized criteria and SC strategies. Fuzzy Multiple Criteria Decision-Making techniques, including FDEMATEL and FANP, were used to structure the causal diagram and prioritize the entire and each section of SC. The case study is an industrial electronic supply chain (ESC) that produces condition monitoring devices. This is the first study on SC strategies for the entire SC and each section separately and implemented in an ESC. In addition, this is one of the few studies on flexibility requirements evaluation in supply chain strategies.

Keywords

Supply chain strategy, Agile supply chain, Supply chain flexibility, FMCDM model, Strategic decision framework.

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******Corresponding author***
Email: mabbasi@mut.ac.ir

1. Introduction

The Supply Chain Strategies (SCSs) that managers consider are interactive with the company's operations and will affect the competitive advantage of SC partners (Hilletofth, 2009; Razmi et al., 2011; Naim et al., 2011). It is not enough to employ a traditional "one-size-fits-all" SCS. Since companies nowadays offer a wide range of products and services in various business environments, no SCS applicable to all types of products and markets. Regarding this fact, every part of SC, including upstream and downstream companies and the focal company of SC, can have different strategies and more than one strategy with different importance weights (Naylor et al., 1999; Olhager, 2003).

Previous studies have an emphasis on the necessity of research on identifying the criteria and factors involved in SC and the different weights of each criterion in SCSs model (Mason-Jones et al., 2000; Zhou et al., 2014; Nag et al., 2014) and Setting the flexibility requirements for types of SCSs. Also, using the decision support models and study on the SCSs in new industry sectors, including healthcare, monitoring, and construction, are suggested (Naim et al., 2011).

A Supply Chain (SC) is a set of added value activities that connect upstream and downstream entities to the customers (Basu et al., 2010). Supply Chain Design (SCD) is defined as: "identifying the desired strategic outcomes for the firm and developing, implementing and managing the resources, processes, and relationships (within the firm and across the supply chain) that seek to make the attainment of such desired outcomes inevitable over time". In today's turbulent world, one of the most critical tools available to managers is SCD and redesign (Melnyk et al., 2014, Huang et al., 2022). The first step in SCD and one of the most important issues in SC studies is to develop competitive strategies between the network partners (Cuthbertson et al., 2012; Ayers, 1999; Wang et al., 2004).

Selecting strategies is a multi-criteria decision, and many internal and environmental criteria should be considered for this decision. There is no consensus on the characterizations and criteria which are effective and differentiate SCSs (Kisperska-Moron et al., 2011). However, these criteria, in general, are distinguished by three decisive factors which determine the strategy of an SC: Demand, Supply, and the general environment (Cuthbertson et al., 2012).

This study provides an analytical approach and a model for managerial decision-making. We selected industrial electronic SC and separately examined strategies for the upstream, downstream, focal company, and entire supply chain. Condition monitoring devices (CMD) supply chain support sensitive equipment to prevent damage, including temperature, pressure, vibration sensors, and other detectors (Lorite et al., 2017; Ing et al., 2013). In the last decade, condition monitoring (CM) industries have been impressed by important structural changes (Lorite et al., 2017; Stetco et al., 2018). Especially Iran's electronic industry with economic conditions by sanctions and the limitations of the budget; that lead them to the restructuring and redesign of their SC, consequently, strategies assessment for the achievement of the best economic and competitiveness situation (Taleizadeh et al., 2017; Lu et al., 2018).

We will examine the literature review in two areas to determine and select the appropriate SCSs to gain a competitive advantage. At first, the typology of SCSs will review and identify the most popular ones (section 2). Second, comprehensive decision criteria that are affecting and determinative in choosing the best strategy will be identified and characterized (section 3). Then we will use the MCDM, including a hybrid of FANP and FDEMATEL techniques, in a case study of the Electronic Industry Supply Chain (EISC) (section 4). Finally, a discussion, managerial implications, and conclusions in Section 5 are presented.

Based on the information we gathered, no study has done this by first suggesting an effective hybrid fuzzy MCDM method by considering all possible details to select appropriate strategies in EISC parts separately and second, examination of SC's criteria (including flexibility requirements) in every type of EISCSs. Also, in the literature, there are some works by these paper hybrid methods (Herat et al., 2012; Ho et al., 2011; Chang et al., 2011). However, there are few and rarely researches that integrate fuzzy set theory, ANP, and DEMATEL. To eliminate expert subjective judgment problems involving complex hierarchical relationships among SCSs selection criteria (Büyüközkan, 2012; Tseng, 2011).

2. Literature review

Since Porter's generic strategies (1985) were introduced for a company to pursue competitive advantage, each company tried to choose and implement the most appropriate competitive strategy according to its situation. Due to the complexity of today's business environment and its constant changes, individual businesses just compete as SCs, not as stand-alone entities (Basu et al., 2010). Several classifications have been proposed for SCSs that have common definitions and principles

Fisher (1997) proposed an 'efficient SC' for functional products and a 'responsive SC' for innovative products. Based on the degree of integration, Frohlich and Westbrook (2001) define five SCSs cluster including inward facing, periphery-facing, supplier-facing, customer-facing, and outward-facing.

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Lee (2002) has identified four SCSs, including efficient, responsive, agile, and Risk-hedging. Katz et al. (2003) have suggested three distinct strategies for an SC, including innovating, modularizing, and appending SCs.

Supply chain council (SCC) (2010), in the Supply Chain Operations Reference model (SCOR), identifies five core SC performance attributes as its strategic orientations, which include reliability, responsiveness, agility, cost management, and asset management.

Parallel to the strategies mentioned, 'Sustainable and green' SCSs with emphasized environmental issues, social responsibility, and conservation of resources for future generations (Srivastava, 2007; Zhu, 2008) and 'resilience' SCS due to the volatility and turbulence in the market (Azevedo et al., 2011; Blackhurst et al., 2011), also presented.

By extension, Naylor et al. (Naylor, 1999) introduced 'Lean' and 'Agile' paradigms as SCSs; For the first time, they combined these two strategies in one SC and raised 'Leagile' or 'Hybrid' SCS. Since their work, lots of studies with different purposes have been done, with the acceptance of this typology for SC (Kisperska-Moron et al., 2011; Agarwal et al., 2006; Goldsby et al., 2006; Christopher et al., 2006; Vonderembse et al., 2006; Carvalho et al., 2011; Rahiminezhad Galankashi et al., 2016; Mittal, 2017).

Other types of SCSs mentioned have common and similar characteristics to the Lean, Agile, and Leagile classifications. Studies have stated that characteristics of 'green SC' (Carvalho et al., 2011; Dües et al., 2013; Larson et al., 2004) and 'resilience SC' (Christopher, 2004) can be implemented respectively with some changes in the ideal forms of the lean and agile SCs. In the following, each of these SCSs will discuss.

Lean SC requires predictable market demand, low product variety, and a long product life cycle. This strategy needs to compress lead time, eliminate all Muda, and develop a value stream to achieve level production (Naylor et al., 1999; Olhager, 2003). Agile SC developed to flexible and quick response to volatile customer's needs. This strategy uses market knowledge and a virtual corporation to exploit portable opportunities in a volatile marketplace. Leagile SC is the amalgam of the lean and agile strategies within an entire SC by positioning the decoupling point to the best suit that needs responding to a fugacious demand downstream yet providing level scheduling upstream from the marketplace (Van Hoek et al., 2001).

Identifying and selecting the most suitable strategy in SC have been examined in some studies, which are summarized and shown in Table 1, according to their techniques and findings.

Table 1. Literature review on SCSs selection

Author(s)	Method and techniques	Findings
Hallgren et al., (2009)	literature review, a software with Visual Basic language	Answers of the firm's manager to 15 questions about the product attributes of one SC, A software will select the most suitable SCS
Herat et al., (2012)	literature review and case study analysis	A framework proposed to select between lean, agile, and leagile SCs, according to the Introduction, Growth, Maturity, and Death lifecycle of products types (functional, innovative, and hybrid)
Chen et al. (2011)	literature review and case study analysis	Proposed a 2×2 matrix according to the demand characteristics (predictable and not predictable) and supply characteristics (lead time conditions) to select between lean, agile, and leagile SCSs and tested in a case study of retail in England
Agarwal et al., (2006)	ANP in FMCG business	According to the network, models and experts determined which supply chain performance criteria should be given priority over others. They also identify that leagile SC is the proper SCS to adopt for their products
Pettit et al., (2010)	AHP and Fuzzy Topsis	According to the quantitative and qualitative attributes selecting the leagile SCS as the best in a case study while the expert opinions of one manufacturing company just have considered
Stetco et al., (2018)	Define hypotheses about the four strategies of SC. Clustering analysis of 125 different companies and The ANOVA test	Choosing and grouping companies between four SCS clusters (lean, agile, hybrid, none of them) based on the alignment between the level of effective supply chain practice and the level of information quality in a 2×2 matrix. In addition, differentiation of business performance measures in each cluster.
Narasimhan et al., (2006)	Cluster analysis and Case analysis	Grouping US manufacturing industries into the four status SCS according to the degree of the material and goods stocks. An industry shows low or high in mentioned inventories depending on its products, processes, and the dynamics of all forces described in the Five Forces Model.
Rahiminezhad et al., (2016)	Nominal Group and AHP Techniques	A framework to evaluate the operational activities of Leagile supply chain strategy. Operational activities of Leagile SCS were determined and categorized with regard to supply chain drivers, and the activities were ranked using an AHP before being categorized using a cycle view of the supply chain.
Mittal et al., (2017)	Entropy approach, VIKOR analysis, and Multi-Objective Optimization on the basis of Ratio Analysis (MOORA) method	Determination of Ten enablers for Lean-Green-Agile Manufacturing System (LGAMS). The influence of these enablers and prioritizing the facilitating capacity of each enabler have been done.
Tirkolaee et al (2020)	Hybrid FANP and FDEMATEL, TOPSIS and Weighted Goal Programming (WGP)	Addressed a sustainable SCS, supplier selection, and order size identification method, and it was tested in a case study of the LED lamps SC
Khan et al., (2022)	interval-valued q-rung orthopair fuzzy combinative distance-based assessment	Five types of green SCSs were investigated and evaluated for food SC, including risk-based, efficiency-based, resource-based, innovation-based, and closed-loop strategy
Tundys & Wi´sniewski (2021)	critical analysis of the literature and simulation methods	Select the most appropriate SCSs to reduce greenhouse gases emissions

By examining these researches, several things were identified: 1) No research evaluates and selects lean, agile, and leagile SC strategies in the electronic industry SC, and the needed flexibility dimensions of throw entire SC have not been prioritized. 2) Past studies have not selected comprehensive criteria for choosing the SCSs; each one depending on their goals, just select only two-three criteria. Functional goals include cost, quality, service level, and lead time. No research has considered environmental conditions and dimensions of flexibility, especially return flexibility, in their models. Finally, 3) the selection of SCSs is a multi-critical decision-making issue with the complexity and high communication between variables.

3. The methodology of SCSs selection

Selecting between SCSs according to the criteria is an MCDM problem with lots of complexity and relationships between criteria. According to these relationships and due to ambiguity in decision-making, we used a literature review, Nominal Technique Group (NTG), and a hybrid of Analytical Network Process (ANP) and Decision Making Trial and Evaluation Laboratory (DEMATEL) with fuzzy values. Figure 1 shows the general view of the research process and methodology.

Briefly, after setting the decision goal, creating a team of experts, specifying the alternatives, and setting the customized decision criteria for evaluation with EISC experts' opinions, we have seven clusters each with a different amount of elements (criteria) inside it. Then we determine the network structure and clusters connections model using the FDEMATEL. After that, we calculate and obtain each cluster's priority vectors of criteria (elements) with inner interdependencies by FDEMATEL; then, we establish outer dependencies and their priority vectors using the FANP. Finally, we construct an unweighted supermatrix based on the interdependencies in the network for every part of SC and the entire SC.

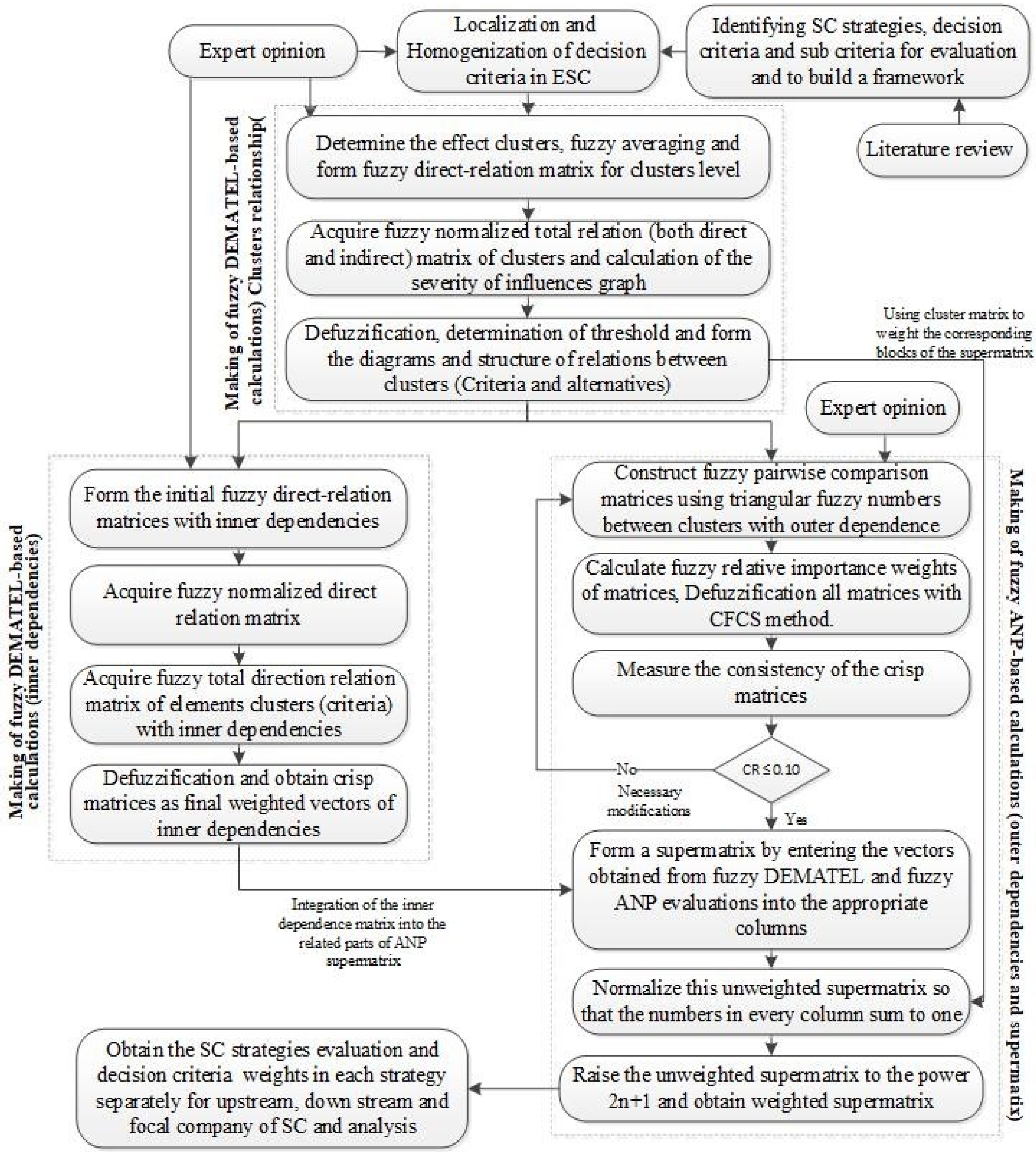

Figure 1. Methodology of SCSs selection

3.1. The FDEMATEL technique

The DEMATEL method originated from the Geneva Research Centre of the Battelle Memorial Institute as a kind of systemic modeling for a problem. When measuring a problem, it can see the cause-effect connections of criteria (Chen-Yi et al., 2007). Although DEMATEL is a good technique for evaluating problems, the crisp values are not enough in the real world. The human judgments with distinctions in decision-making are often uncertain and rigid to guess by accurate numerical values, causing the fuzzy logic requirement (Lin et al., 2004).

Thus, fuzzy theory (Zadeh, 1965) is applied to the DEMATEL technique for answering such an MCDM subject. FDEMATEL method is used in the literature (Büyüközkan et al., 2012; Chang et al., 2011; Lin et al., 2004). In this paper, the steps of group FDEMATEL is according to the Lin and Wu (2004) research.

3.2. The FANP technique

ANP is a general form of the Analytical Hierarchy Process (AHP) that considers the dependence between the elements. Instead of a hierarchy, the ANP-based system is a network that replaces single-direction relationships with dependence and feedback (Saaty, 2008). The ANP uses a reciprocal pairwise comparisons scale.

A network has clusters (categories) of elements (criteria), with the elements in one cluster being connected to elements in another cluster (outer dependence) or the same cluster (inner dependence). An arc denotes the interactions between two clusters, and a loop indicates the inner dependence of elements within a cluster.

As mentioned that human decisions about priorities are often unclear and rigid to guess by crisp values; again, fuzzy values are indispensable for considerate subjects structured by ambiguity. Therefore, using a combination of fuzzy set theory and ANP for SCSs assessment. In the literature, many researchers, such as [Liu et al., 2009; Vinodh, 2011] applied FANP to several research fields. In this paper, the steps of FANP is according to the Buyukozkan and Cifci (2012), Saaty (2008), and Zhou (2012) researches.

3.3. Decision criteria of the SCSs selection framework

To find and define the decision criteria for SCS selection, we examined studies from scientific databases (e.g., EBSCO, Scopus, Google scholar); with keywords including 'SCS', 'SCD', 'lean, agile, leagile SCs', 'green, sustainable, resilience SCs', 'SC performance' and with an emphasis on industrial electronic SCs.

Although wide studies on lean, agile, and leagile SCSs have been done, there is no consensus on the criteria of SCSs. But all studies' criteria are in three general categories, including 'Supply characteristics', 'Demand characteristics', and 'Environmental conditions' of SC. Supply characteristics have three subcategories: ' Objectives of supply', 'Process characteristics of supply', and 'Product characteristics of supply' (Basu et al., 2010).

After literature review and extracting all the possible criteria in each category, experts' opinions of the case study have been taken through the NGT (Delbecq, 1986) to customization and specialization of decision criteria for the electronic industry. Each criterion was evaluated in terms of 'related or not', 'overlapping' or 'common concept' with another, 'need to change the title', 'very low importance', 'hierarchy of categorized', and 'adding new one'. Finally, some criteria were eliminated, some were changed, some were merged, and some new ones were added. Table 2 shows the final decision criteria of the research, with their sources, definitions, and categories. These criteria will be used to develop the framework of SCSs selection.

Table 2. Literature review of decision criteria on EISCS selection

Category (cluster)	Criteria	Sources	abbrev
Supply characteristics-Objectives- (GSC)	Cost	Wang et al., (2004); Pooya et al., (2017); Liu et al., (2010)	CO
	Profit	Harrison et al., (2008); Rimienė (2011); Frohlich et al., (2001)	PR
	Customer satisfaction	Ho et al., (2011); Fisher (1997)	VCS
	Efficiency	Niosi et al., (1992)	EF
	Quality	Porter (1985); Naylor (1999)	QT
	Speed and Swiftness	Stetco et al., (2018); Swafford (2006)	SD
	Responsiveness	Razmi et al., (2011); Delbecq (1986)	RS
	Market sensitive and Alertness	Hilletofth (2009); Bruce (2004)	MS
	Lead time	Gunasekaran et al., (2001); Thornton (2012)	LT
	Adaptability	Agarwal et al., (2007); Christopher and Jüttner (2000)	AD
	Certainty	Goldsby et al., (2006); Brun et al., (2017)	UC
	Reliability	Christopher and Jüttner (2000); Hilletofth (2009)	RE
	Service level	Büyüközkan (2012); Christopher and Jüttner (2000)	SL
	Innovation	Chang et al., (2011); Christopher (2004)	IN
Supply characteristics-Flexibility- (FSC)	Operation and system flexibility	Vonderembse et al., (2006); Rimienė (2011)	PFL
	Supply flexibility	Carvalho et al., (2011); Dües (2013); Chien et al., (2007)	SFL
	Delivery flexibility	Namulanda et al., (2018)	DFL
	Return flexibility	Christopher and Jüttner (2000)	RFL

Category (cluster)	Criteria	Sources	abbrev
Supply characteristics-process- (PSC)	Customization	Vinodh et al., (2011); Stetco et al., (2018)	CU
	Strategic Stock	Azevedo et al., (2008)	SS
	Decisiveness	Gunasekaran et al., (2008); Huang et al., (2002)	DE
	Postponement	Christopher and Jüttner (2000)	PP
	Surplus capacity	Chang et al., (2018); Stetco et al., (2018)	CS
	Process integration	Taleizadeh et al., (2017);	PIG
	IT integration and accessibility	Van et al., (1983)	ITIG
	Virtual Networking	Hallgren et al., (2009)	VN
	Alliances and Cooperation	Christopher and Jüttner (2000); Hilletofth (2009)	PA
	Waste eliminating	Thornton (2012); Chang et al., (2018)	WE
	Smooth operation flow	Harrison et al., (2008)	SOF
	Continuous Replenishment	Christopher and Towill (2001)	CR
	Employees skills	Gunasekaran et al., (2001)	HR
Supply characteristics-Product- (OSC)	Innovative product	Srivastava (2007); Chen et al., (2011)	IP
	Standard and Functional product		SP
	Hybrid product		HP
Demand characteristics (DC)	Stable and predictable	Gabus et al., (1973)	SPD
	Variable and unpredictable		VD
Environmental conditions (ECC)	New foreign threats	Opricovic et al., (2003); Lorite et al., (2017); Research expert opinions.	FNT
	International sanctions	Research expert opinions.	IS
	Environmental problems	Zhu et al., (2008)	EP
	government regulations	Zadeh (1965); Research expert opinions.	RR
	Electronic industry budget	Zadeh (1965); Research expert opinions.	DDB
	National security conditions	Zadeh (1965); Research expert opinions.	SC

4. Application of the SCSs selection in EISC

In nature, electronic industries have high investment, high levels of knowledge and technology, knowledge base human resources, equipment with a long lifecycle, and high maintenance costs and are more expensive than other industries. Trial and error in the design of this industry's SC result in high costs, and missed opportunities will be significant (Thornton, 2012).

Nowadays, electronic industries have faced structural changes in condition monitoring, which include: Notice of the latest status of equipment in the form of online, controlling equipment hazards in the workplace, uncertainty in demand and sensitive equipment needs in terms of speed and variety, transformation in infrastructures, industrial and research capabilities (Lorite et al., 2017, Stetco et al., 2018), intense activities of electronic industries competitors including China, India, USA, and European Union through investment to development CMD production and exports (Stetco et al., 2018), in addition, changes in Iran I.R. economic conditions and the limitations of the budget. The total environment changes indicate that the current structures of the electronic industry need a change to achieve the required competitive advantages. Evaluation previous studies shown that to cope with these changes, electronic industries of other countries have examined restructuring and redesigning their SCs (Liu et al., 2010; Lu et al., 2018; Chien et al., 2007).

Ministry of Energy (MOD) of IRI is responsible for planning, supporting, producing, and developing facilities and electronic equipment of relative companies by its affiliated organizations. One of the main organizations affiliated with this ministry is Iran Electronics Industries (IEI). IEI works on producing different kinds of electronic products, including electrical boards and components, instrumentation, PLC, and controllers. According to the expert's opinions, SC of individual small monitoring devices and their instrumentations in the electronic industry has the strategic and unique position that serves all rotary and static equipment (pumps, compressors, turbines, tanks, valves and etc.), a wide variety of products from standard to innovative and multiple suppliers that shown the priority to redesign and assessing and selecting the most appropriate strategies in this industry section. The network of SC and upstream, focal company, and downstream of the case study ESC is shown in Figure 2.

Decision makers were 10 people, including managers and top advisers of the firms of the selected SC, separately, four people from upstream companies of SC, four people from downstream companies of SC, and two from a focal company of SC, according to the research objectives. Due to the order fulfillment (Opricovic et al., 2003; Huang et al., 2002), the focal

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company was the central company of the SC that concentrates on assembly and key components manufacturing (Chiu et al., 2009).

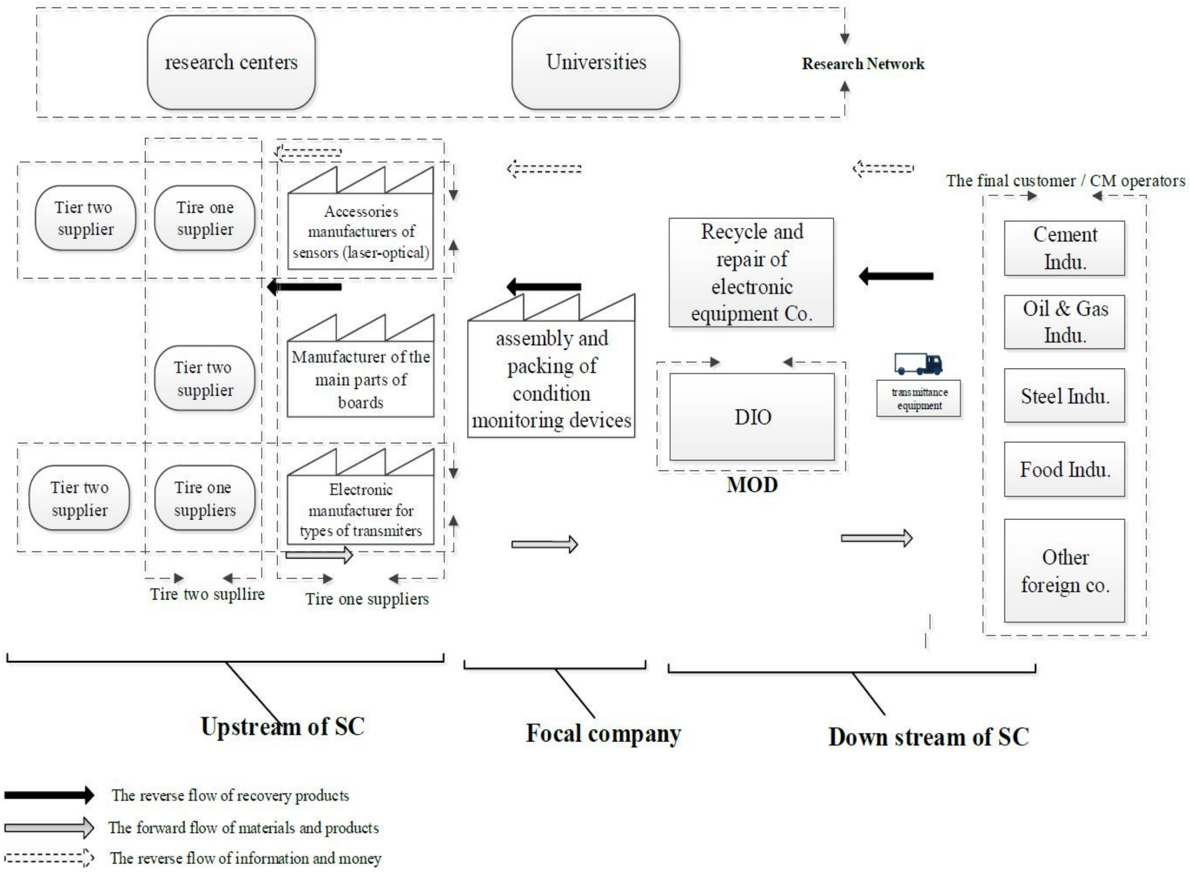

Figure 2. The general view of the ESC case study

4.1. The steps of the EISCSs selection and formulations

According to the previous sections, after setting the decision goal, create a team of experts, specify the alternatives, and set the customized decision criteria for evaluation with EISC expert's opinions; in this study, we have seven clusters that each have a different amount of elements (criteria) inside it. The following steps are as below:

Step 1. Determination of the network structure and clusters connections model: this step uses the FDEMATEL according to the sub-steps and equations below:

Step 1.1: Acquire fuzzy direct-relation matrices. Experts make sets of pairwise comparisons according to the linguistic terms and equivalent positive triangular fuzzy values scale in the study of Lee (2002) regarding influence and direction between clusters.

So obtained 10 fuzzy 7×7 matrices $\widetilde{Z^1}$, $\widetilde{Z^2}$…$\widetilde{Z^{10}}$, for example, the matrix $\widetilde{Z^1}$ for expert No. 1; Where $\widetilde{Z_{ij}^1}$ = (lij, mij, uij) are triangular fuzzy numbers. Elements $\tilde{Z}_{ii}$ (i = 1, 2… n) will be regarded as a triangular fuzzy number (0, 0, 0) whenever it is necessary. Then acquired average fuzzy matrix $\tilde{Z}$ according to the fuzzy arithmetic rules (Lee, 2002). Fuzzy matrix $\tilde{Z}$ is called the initial direct-relation fuzzy matrix.

Step 1.2: Acquire normalized fuzzy direct-relation matrix. On the base of the direct-relation matrix$\tilde{Z}$, the normalized direct-relation matrix $\tilde{X}$ can be obtained through the linear scale transformation (Eq.1).

$$\tilde{a}_i = \sum_{j=1}^{n} \check{z}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right),\ r = \max_{1\le i\le n}\left(\sum_{j=1}^{n} u_{ij}\right)$$

$$\tilde{x}_{ij} = \frac{\check{z}_{ij}}{r} = \left(\frac{l_{ij}}{r}, \frac{m_{ij}}{r}, \frac{u_{ij}}{r}\right) \qquad (1)$$

Step 1.3: Acquire a fuzzy total-relation matrix. As soon as the normalized direct-relation matrix $\tilde{X}$ is obtained, the total-relation matrix $\tilde{T}$, can be acquired by using the following formulas (Eq. 2) according to the proof of Lin & Wu (Lin, 2004) and the rules of Lee (Lee, 2002), Kuafman and Gupta (1991), and Laarhoven & Pedrycz (Laarhoven et al., 1983), in which the I is denoted as the identity matrix (Eq.2).

$$\tilde{T} = \begin{bmatrix} \tilde{t}_{11} & \tilde{t}_{12} & \cdots & \tilde{t}_{1n} \\ \tilde{t}_{21} & \tilde{t}_{22} & \cdots & \tilde{t}_{2n} \\ . & . & \cdots & . \\ \tilde{t}_{n1} & \tilde{t}_{n2} & \cdots & \tilde{t}_{nm} \end{bmatrix} \qquad (2)$$

$$\tilde{t}_{11} = (l'_{ij}.m'_{ij}.u'_{ij})$$

All fuzzy calculations in these steps were done through the EXCEL. Inverse matrix and matrices multiplications were done by the Matrix Calculator Pro Ver. 3.5 software.

Step 1.4: Defuzzification and acquire the causal diagram. We apply the CFCS method by Opricovic and Tzeng (2003) for the defuzzification of the fuzzy values of the matrix $\tilde{T}$ and obtain the total relation definite matrix T (Table 3). The CFCS method has many advantages over other means (Lin et al., 2004). Then the causal diagram is constructed with the horizontal axis ($\tilde{D}_\iota$+$\tilde{R}_\iota$) def. named 'Prominence' and the vertical axis ($\tilde{D}_\iota$-$\tilde{R}_\iota$) def. named 'Relation' (columns nine and ten of Table 3). In the SC case study, it is clear that 'Environmental conditions', 'Demand characteristics' and 'Product characteristics' clusters are the cause group, and 'Strategies alternatives', 'Process characteristics', 'Flexibility types', and 'Objectives' clusters are in the effect group. From this point of view, ‘Environmental conditions’ has the highest impact on the ‘Strategies alternatives’, ‘Objectives’, and ‘Flexibility types’.

Table 3. The total relation crisp matrix T and the values of $(\widetilde{D}_i+\widetilde{R}_i)^{def.}$ and $(\widetilde{D}_i-\widetilde{R}_i)^{def.}$

T	ASC	GSC	FSC	PSC	OSC	DC	ECC	$(\widetilde{D}_i+\widetilde{R}_i)^{def.}$	$(\widetilde{D}_i-\widetilde{R}_i)^{def.}$
ASC	0.30	0.42	0.44	0.39	0.40	0.22	0.22	5.03	-0.28
GSC	0.37	0.25	0.38	0.33	0.35	0.16	0.16	4.65	-0.55
FSC	0.39	0.39	0.29	0.38	0.37	0.17	0.16	4.97	-0.62
PSC	0.43	0.43	0.45	0.30	0.42	0.23	0.21	5.03	-0.06
OSC	0.35	0.34	0.39	0.36	0.25	0.20	0.16	4.67	0.01
DC	0.40	0.37	0.42	0.40	0.40	0.16	0.19	3.83	0.91
ECC	0.47	0.47	0.50	0.45	0.46	0.29	0.20	4.24	1.49

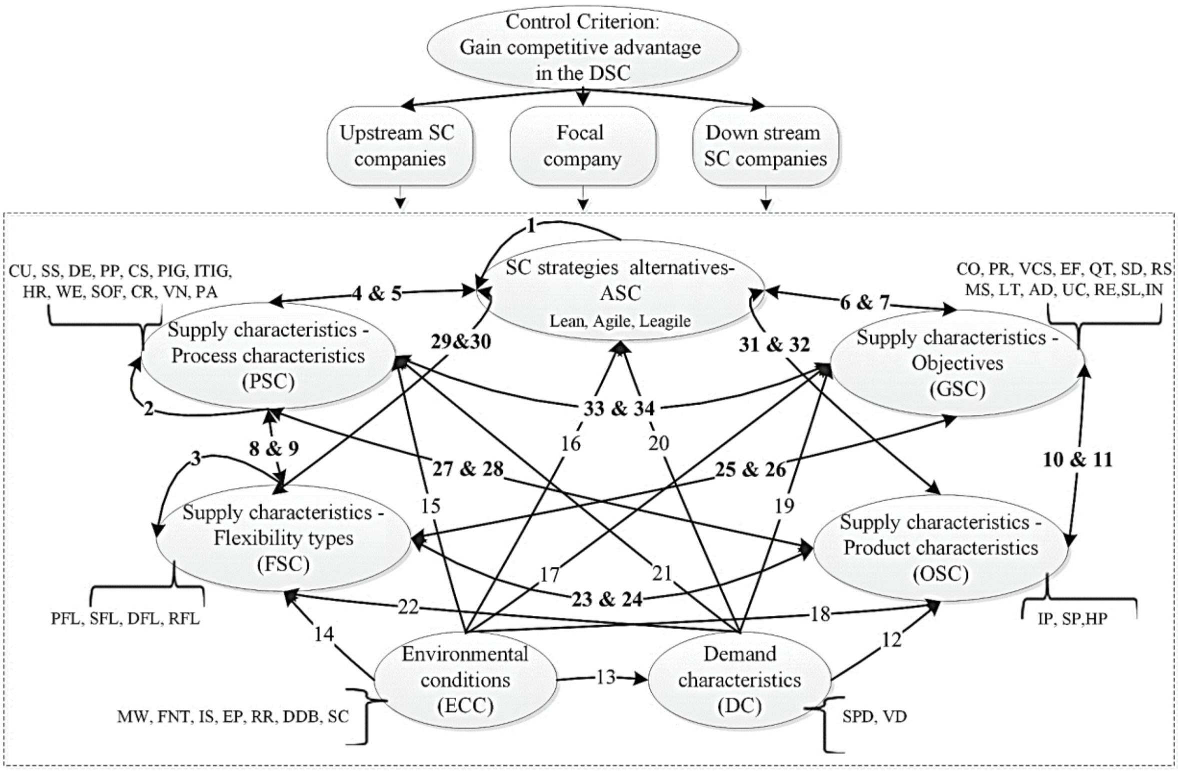

Figure 3. The detailed diagram structure and relations between clusters to SCSs selection

Step 1.5: set a threshold value and develop the structural model and diagram of relations. In practice, if all the information from matrix T converts to the diagram, the map would be too complex to show the indispensable information for decision-making. To reduce the complexity of the diagram, the decision-maker sets a threshold value ‘α’ for the influence level: only factors whose influence value in matrix T is higher than the threshold value can be chosen and converted into the diagram. The threshold value can be decided through the brainstorming of experts. When the threshold value and relative diagram have been decided, the diagram can be shown (Yang et al., 2008; Huang et al., 2010). In this paper, the threshold value is 0.29 according to the expert’s opinions, and matrix T_α was obtained by filtering the minor effects denoted by the factors of matrix T. According to the matrix T_{α}, we can form the diagram of relationships between clusters, shown in Figure 3.

From the next step until the end, all calculations will have done separately for three parts of SC experts, including the focal company and upstream and downstream companies.

Step 2: Calculate and obtain each cluster's priority vectors of criteria (elements) with inner interdependencies by FDEMATEL. According to Figure 3, there are three clusters with inner dependencies that experts have answered to a set of pairwise comparisons to determine the effect of criteria X1 to X2 of each cluster element for SC to gain competitive advantages. All sub-steps of this step are the same as the first four substeps of step one. Due to abound of data, results were just shown for one cluster with inner dependency and for one part of SC; other calculations just did in the same way. Table 4 (columns 1 to 4) shows the fuzzy values matrix sample, completed by the expert of downstream SC, for flexibility types of SC cluster. Columns 5 to 8 show the defuzzified normal total relation sample matrix for mentioned cluster and then the inner dependencies of all three total relation matrices, as the priority vectors, can be obtained to locate in the unweighted supermatrix of ANP afterward; and can be seen in Figure 4 as matrices ‘1’, ‘2’ and ‘3’ of the supermatrix.

Table 4. The fuzzy values matrix sample for flexibility types of SC cluster

Cn.No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
	$\widehat{Z}^1{}_3$				$\widetilde{T}_3^1$				**AG**	
	PFL	**DFL**	**SFL**	**RFL**	**PFL**	**DFL**	**SFL**	**RFL**	**Fuzzy weights** $\widetilde{W}_3^1$	**Final weights** W_3^1
PFL	(0,0,0.25)	(0.5,0.75,1)	(0,0.25,0.5)	(0.5,0.75,1)	0.19	0.29	0.27	0.31	(0.18,0.23,0.30)	0.24
DFL	(0,0,0.25)	(0,0,0.25)	(0,0,0.25)	(0.25,0.5,0.75)	0.10	0.09	0.11	0.18	(0.54,0.62,0.69)	0.63
SFL	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	(0.25,0.5,0.75)	0.34	0.30	0.21	0.29	(0.05,0.04,0.07)	0.04
RFL	(0.5,0.75,1)	(0.5,0.75,1)	(0.5,0.75,1)	(0,0,0.25)	0.36	0.32	0.41	0.23	(0.07,0.09,0.12)	0.09

Step 3: Establish outer dependencies and their priority vectors using the FANP. In this step, 202 matrices were completed according to the outer dependencies between clusters and related criteria in Figure 3 for every expert.

Step 3.1: Distributing and collecting pairwise comparison questionnaires. In this step, a pairwise comparison was made according to the fuzzy linguistic scale of Zhou (2012), in which experts compared the influence of criteria in a cluster on criteria in another cluster with respect to a control criterion.

Step 3.2: Compute the respective importance weight vectors. The priority vectors for each pairwise comparison matrix must fill the various supermatrix submatrices. Approximate triangular fuzzy priorities $\widetilde{W_k}$, where k = 1, 2. . . , n, from the opinion matrix. After averaging related fuzzy matrices of each part of SC; such as the example, the fuzzy weight is obtained by applying Equation 3 calculations on the averaged fuzzy matrix of the FSC cluster with respect to agile SCS, as the 9th column of Table 4. The logarithmic least-squares method can calculate these weights (Eq.3) (Büyüközkan, 2012).

$$\widetilde{W_k} = (w_1^k . w_k^m . w_k^u) \quad k = 1, 2, \ldots, n$$

$$w_s^k = \frac{\left(\prod_{i=1}^{n} a_{kj}^{s}\right)^{1/n}}{\sum_{i=1}^{n}\left(\prod_{i=1}^{n} a_{ij}^{m}\right)^{1/n}} . s \in \{l . m . u\} \tag{3}$$

Then the CFCS method (Kauffman et al., 1991) was applied for the defuzzification of the fuzzy values, and defuzzified weights were obtained according to the 10th column of Table 4.

With respect to the other SCSs and obtaining weighted vectors, the result of this evaluation will form matrix '30' of supermatrix, which can be seen in Figure 3. Other evaluations for all matrices separately for all parts of SC are calculated similarly.

Step 3.3: Calculate the consistency ratio of all matrices. In order to control the result of the method, The Consistency Ratio (CR) is used to directly estimate the stability of the pairwise comparisons and should be less than 0.10. Then it will be tolerable comparisons (Saaty, 2008). In this study, the inconsistency ratios for all the comparison matrices were calculated according to the Büyüközkan et al. (2012) research.

For needed adjustments to improve the consistency of the matrices with inconsistency, the related matrix with highlighted values that caused inconsistency returned to the related decision maker, and this process continued until all matrices were consistent.

Step 4: Construct an unweighted supermatrix based on the interdependencies in the network for every part of SC and the entire SC. The supermatrix is a partitioned matrix in which each submatrix is composed of a set of inner (FDEMATEL) and outer (FANP) relationships between dimensions and attribute-enablers in the graphical model. All weighted vectors insert in Super Decision software to form an unweighted supermatrix for each part of SC. The unweighted supermatrix of the entire SC was calculated by averaging the unweighted supermatrix of three parts, including ${W_f}^1 . {W_f}^2$ and ${W_f}^3$ (Eq.4) (Yang et al., 2008).

$$W_f = \frac{1}{3}{W_f}^1 + \frac{1}{3}{W_f}^2 + \frac{1}{3}{W_f}^3 \tag{4}$$

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A total supermatrix is shown in Figure 4, with the attention representing the several connections from Figure 2; for instance, '30' is the submatrix that shows the influence relationship among FSC types (elements) and SCSs with respect to the competitive advantages as control criteria. Blank sections of the supermatrix mean they had no relationships and calculations.

	ASC	GSC	FSC	PSC	OSC	DC	ECC
Supply chain strategies alternatives (ASC)	1	7	29	4	32	20	16
Supply chain objectives (GSC)	6		25	33	11	19	17
Supply chain flexibility (FSC)	30	26	3	8	24	22	14
Supply chain process characteristics (PSC)	5	34	9	2	28	21	15
Supply chain product characteristics (OSC)	31	10	23	27		12	18
Supply chain demand characteristics (DC)							13
Supply chain environmental conditions (ECC)							

Figure 4. General priority vectors submatrix notation for supermatrix

Step 4.1: Acquire the weighted supermatrix for each part of SC and the entire SC. Saaty (2008) stated that to obtain the weighted supermatrix, paired comparisons on the clusters perform as they influence each cluster to which they are connected with respect to the given control criterion. The derived weights are used as weights of the elements of the corresponding column blocks of the supermatrix. Assign a zero when there is no influence. Thus, obtain the weighted column stochastic supermatrix. In this paper, the normalized cluster weights matrix (T_{α}) was obtained by FDEMATEL in sub-step 1.4, according to Yang et al. (2008). Then, they are normalized and entered into super decision software to calculate the weighted supermatrix of each part of SC (${W^1}_w$,${W^2}_w$ ${W^3}_w$) and the entire SC (W_W).

Step 4.2: Limit the weighted supermatrix by raising it to a sufficiently large power k and extracting results. Overall weights of the criteria and strategies of each part of SC and entire SC were obtained by multiplying the related weighted supermatrix by itself until the values of each row converge to the same value for every column of the supermatrix. In this case, the supermatrix is raised to power 96. Then limited priorities values normalized to one. We choose any column from the stable limit supermatrices as the final weights of interdependency indicators, as shown in Table 5. The limit-normalized supermatrices are given separately for downstream companies(${W^1}_T$), upstream companies(${W^2}_T$), the focal company (${W^3}_T$) and entire (W_T) SC.

5. Results and discussion

The main goal of this study is to suggest an effective hybrid fuzzy MCDM approach with considering all possible details to select appropriate strategies and evaluation related criteria in each strategy, especially flexibility types of an SC. Based on the literature review and expert confirmation, possible SCS criteria were described, and a new systemic model was prepared.

Table 5. Final results of normalized limited priorities separately for parts and entire of SC

Clusters (categories)	Criteria	Entire SC(W_T)	Focal company of SC ($W^3{}_T$)	Upstream companies of SC ($W^2{}_T$)	Downstream companies of SC ($W^1{}_T$)
ASC	Lean	0.0607	0.059	0.078	0.043
	Agile	0.0770	0.064	0.057	0.108
	Leagile	0.0794	0.096	0.076	0.062
GSC	CO	0.0073	0.008	0.008	0.004
	PR	0.0069	0.009	0.006	0.003
	VCS	0.0229	0.028	0.024	0.018
	EF	0.0105	0.009	0.012	0.009
	QT	0.0141	0.013	0.018	0.011
	SD	0.0112	0.016	0.009	0.009
	RS	0.0189	0.015	0.017	0.026
	MS	0.0121	0.011	0.012	0.013
	LT	0.0096	0.008	0.009	0.011
	AD	0.0167	0.014	0.014	0.023
	UC	0.0091	0.010	0.010	0.006
	RE	0.0139	0.015	0.016	0.011
	SL	0.0129	0.013	0.010	0.015
	IN	0.0153	0.015	0.010	0.022
FSC	PFL	0.0838	0.084	0.074	0.089
	DFL	0.0530	0.048	0.052	0.058
	SFL	0.0424	0.034	0.055	0.038
	RFL	0.0541	0.058	0.053	0.050
PSC	CU	0.0172	0.013	0.017	0.024
	SS	0.0093	0.010	0.011	0.006
	DE	0.0123	0.010	0.014	0.014
	PP	0.0208	0.026	0.019	0.022
	CS	0.0115	0.013	0.011	0.012
	PIG	0.0163	0.017	0.014	0.018
	ITIG	0.0184	0.017	0.019	0.023
	VN	0.0146	0.013	0.017	0.015
	PA	0.0174	0.018	0.018	0.017
	WE	0.0129	0.015	0.016	0.010
	SOF	0.0095	0.012	0.013	0.005
	CR	0.0117	0.011	0.014	0.013
	HR	0.0187	0.016	0.019	0.022
OSC	IP	0.0649	0.055	0.055	0.080
	SP	0.0430	0.050	0.048	0.030
	HP	0.0700	0.075	0.072	0.063

For the secondhand goal of the study, we consider SC strategies of DI. For national supply, electronic industries must be able to compete with threatened countries and gain competitive advantages over them. In this regard, selecting the right strategies and implementing the appropriate policies are inevitable necessities for them.

Based on our information, no research has been done on such subjects in ESC by comprehensive techniques with DEMATEL and ANP in a fuzzy environment. The presented system can be used to further MCDM subjects and case studies.

According to the result of this study in Table 6, we developed the flexibility requirements of lean, agile, and leagile in the EISCs, which was a gap in the literature research (Naim et al., 2011).

Table 6. Flexibility requirements of lean, agile and leagile of EISCs

Flexibility types		Leagile	Lean	Agile
Operation and system flexibility	PFL	M	L	H
Delivery flexibility	DFL	M	M	H
Supply flexibility	SFL	M	H	L
Return flexibility	RFL	H	M	M
	H=high		M=medium	L=low

5.1. Discussion on the industrial electronic SC results

Hilletofth (2009) has argued that companies must use several SC solutions concurrently (i.e., develop a differentiated SCS) to stay competitive in today's fragmented and complex markets. Results of this study show that the 'leagile' strategy is applied to the entire EISC and focal company, but there are considerable weights for other strategies too. Downstream of SC select 'Agile' SCS as the first, and upstream of SC select 'Lean', and very close it leagile as the first. This study addresses employing several SCSs concurrently with different weights of criteria to consider, that can develop and manage these multiple SCSs.

Brun et al. (2017) expressed that after 'readiness' and 'responsiveness' for EISC, according to the budget restriction, 'Cost' control is critical. In this study, 'Cost' is not recognized as a very important criterion in each level of SC. It may be because of governmental companies in SC that have no problem with financing and funding. Privatization may help this SC to assess its financial situation with more concern.

Operation and system flexibility in every part of SC has the highest priority, but in agile SC, the weight differences between each part are more essential. Return flexibility is at the next level of priority in EISC. In electronic industrial SCs dealing with security issues, flexibility in returned repair parts and used equipment is indispensable. Delivery flexibility has an approximately equal priority with return flexibility, and supply flexibility is at the end of the priority. The electronic industry has a closed loop SC with special products regarding the high-security level of information, high technology, technical knowledge, and the need for high investment. In this situation, the ability and permission to enter a supplier in this SC are not easy (Stetco et al., 2018). Especially, Iran is under sanctions pressure which caused few foreign supplier connections, so supply flexibility in EISC has the lowest priority.

5.2. Limitations and future research suggestions

The limitation of this research is the number of decision-makers in the EISC. This research proposes all proven models of the hybrid of two techniques in a fuzzy environment to reduce the number of pairwise questionnaires and remove restrictions of ANP. But many criteria and their connections in this framework need the decision maker's cooperation.

This framework can be used in other multi-tier and more complex SCs. Future research offers opportunities for SCSs in return process remanufacturing material flow in a closed loop or other kinds of SCs in which SC partners have different strategies as a reverse SC. Also, according to the variety and types of products, especially for upstream companies of SC, there are multi-decoupling points that can be determined.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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