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SOFT COMPUTING IN DECISION MAKING AND IN MODELING IN ECONOMICS

A Markovian-based fuzzy decision-making approach for the customer-based sustainable-resilient supplier selection problem

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Abstract
The supplier selection problem is one of the most important issues in supply chain management. So, many papers have investigated the mentioned problem. However, the related literature shows that researchers had less attention to the sustainability and resilience aspects based on the customer preferences in supplier selection problem. To cover this gap, this research tries to investigate the customer-based sustainable-resilient supplier selection problem. In this way, a Markovian-based fuzzy decision-making method is proposed. At the outset, the customer preferences are evaluated using a combination of the quality function deployment and the Markov transition matrix. Then, by combining the transition matrix and the fuzzy best–worst method, the weights of the indicators are calculated. Finally, the decision matrix is formed and the performance of suppliers is measured based on the multiplication of the decision matrix and vector of sub-criteria weights. Regarding the recent pandemic disruption (COVID-19), the importance of online marketplaces is highlighted more than the past. Hence, this study considers an online marketplace as a case study. Results show that in a pandemic situation, the preferences of customers when they cannot go shopping normally will change after a while. Based on the Markov steady state, these changes are from the priority of price, availability, and performance in initial time to serviceability, reliability, and availability in the future. Finally, based on the FBWM results, from the customer point of view, the top five sub-criteria for sustainable-resilient supplier selection include cost, quality, delivery, responsiveness, and service. So, based on these priorities, the case study potential suppliers are prioritized, respectively.

Keywords Supplier selection · Sustainability · Resilience · Customer preferences · FBWM · Markovian-based decision-making

1 Introduction

In today's competitive market environment, the importance of supply chain management (SCM) to obtain competitive advantage is not hidden from anyone. In this field, the supplier selection problem (SSP) is known as one of the most important issues (Fallahpour et al. 2018). At first, only the economic aspects of the mentioned problem were important for supply chain managers. But, some reasons such as minimizing the Greenhouse gas emissions led to attracting the attention of researchers to the green aspects of the supply chain management (Dogan and Seker 2016; Dogan and Turkekul 2016; Dogan and Inglesi-Lotz 2017; Waqas et al. 2018a, 2021; Ullah et al. 2021). In this regard, in recent years, by increasing concern about sustainable development measures, the Sustainable Supplier Selection Problem (SSSP) has become a trend in the SCM problem (Moheb-Alizadeh and Handfield 2019). In general, sustainability attempts to incorporate social, environmental and economic aspects in the problem, simultaneously (Waqas et al. 2018b). Over the past twenty years, sustainability was one of the main concerns of manufacturing industries to decrease environmental damages, and

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improve the loyalty of the customers (Sazvar et al. 2021). In the SSSP, supply chain's leaders consider economic, environmental, and social factors for selecting the best suppliers (Jia et al. 2020). Considering sustainable development measures is able to gain a good view from the firm to customers that lead to increase customers' loyalty and profits (Coşkun et al. 2022; Xing et al. 2022).

On the other hand, supply chains are always faced with natural and man-made hazards, and sometimes these disasters lead to many disruptions in supply chain processes (Mamashli et al. 2021b, a; Nayeri et al. 2021). Hence, considering a plan to deal with these disruptions can improve the decision-making process to decrease the risk of businesses, drastically (Majumdar et al. 2021; Hu et al. 2022). In this regard, researchers recently introduced the resilient supplier selection problem in which some measures are defined about the resilience of the suppliers (Amindoust 2018a). Davoudabadi et al. (2020) defined the resilience of suppliers as the capability of suppliers to handle risks and to improve the position of the firm regarding the competitors in terms of tackling disturbances. For example, Philips was a chip plant in Albuquerque that supplied for both Nokia and Ericsson manufacturers. In 2000, the production capacity of Philips was destroyed via fire. However, Nokia decided on new supply plans and did not believe that Philips can come up with this disruption soon and it may affect Nokia production. So that, it selected another supplier as soon as possible but Ericsson was had been waiting and did not do anything. After several weeks, Ericsson was faced with a loss of over 400 million dollars (Zsidisin and Wagner 2010). Furthermore, the aforementioned instance demonstrates the importance of the resilient SSP.

Besides, considering customer preferences is very important in supplier selection problem due to the importance of customer requirements. Better supplier causes better materials and better products that satisfy customer preferences and requirements, consequently. Based on this, identifying and prioritizing customer requirements and technical requirements is a multi-criteria decision-making process that includes qualitative and quantitative criteria and has become more important with the increasing of competition in market. For identifying the customer requirements, Quality Function Deployment (QFD) is very popular. QFD is one of the qualitative tools to achieve the needs and demands of the customer, which starts from studying the market and identifying the customers of the product, and while identifying the demands and needs of the customers, it tries to take them into account in all stages of design and production so that the services and products match the customer preferences. Since these requirements should be prioritized, many researches used Fuzzy logic for prioritization of requirements and criteria due to human thinking limitation. Fuzzy logic is a mathematical topic introduced by (Zadeh 1965). It tries to be as close as possible to human thinking and perception. It is based on the assumption that humans do not usually think in terms of zero and one (yes/no), but distinguish a wide range of "vague" values (almost true, very true, yes, maybe no, yes and no). In addition, the preferences of customers always have been changing during the period of consumption (Chang 2022). In this situation, using the Markov chain is seemed to be useful. So that in the Markov chain matrix, the preference level of customers (criteria which are important for customers) within several periods can be considered (Nawaz et al. 2018). Based on the literature, few studies are considered customers' preferences in the SSP (see (Asadabadi 2017; Pramanik et al. 2017a; Tavana et al. 2017)). However, this concept in real problems is so functional and important (Asadabadi 2017). Decision-making with considering the initial preferences of customers may cause a wrong decision in the next periods. It is due to the changeable characteristics of customers because of their priority changes. The probability that a customer will remain in his priority several years later is very low. So that his preferences stages must be calculated in an n-step transition probability matrix which is easy to be calculated in Markov chain approach.

Nowadays, electronic procurement from online marketplaces has become one of the major parts of supply chain management (You et al. 2017a, b). An online marketplace is a store where several sellers try to sell their products and services through a website and there are diverse customers. Some people prefer to buy their commodities from these markets since they are accessible every time and there is no need to go physically and more visibility is for comparing different products. In some situations, like pandemics, the benefits of online marketplaces become more significant than other normal situations. Recently, the coronavirus (COVID-19) outbreak caused a global pandemic. Statistics show that online shopping has taken an unbelievable level of societal importance during this period (Erjavec and Manfreda 2022; Tavakoli et al. 2022a, b, 2023). So, it is necessary to focus on these kinds of markets in this special pandemic situation. These market places supply their inventory for selling to their customers from different and heterogeneous suppliers. The crucial problem is to select the best suppliers based on customer needs. Supplier selection in online marketplaces actually is more challenging because of more risk and uncertainty in this kind of market.

It should be noted that the combination of resilience and sustainability in the context of the SSP while customer preferences is considered is rare and there are few papers that considered three aforementioned concepts, simultaneously (see Amindoust 2018; Kaur et al. 2018; Alikhani et al. 2019; Zavala-Alcívar et al. 2020)). Moreover, customer-based resilient-sustainable supplier selection necessitates many different criteria (which might be conflict) for evaluating the potential suppliers. Therefore, developing a sustainable-resilient supplier performance evaluation model is an indispensable need for the policy makers of industries to make the right decisions (Shao et al. 2022).

Furthermore, this paper addresses the Customer-based Sustainable-Resilient Supplier Selection Problem (CSRSSP) using a combination of the Markov chain, QFD, and fuzzy MADM methods. For this purpose, first, we identify the main indicators, which are related to the research problem. Afterwards, the transition matrix is formed based on customers' preferences applying integrated Markov chain, and QFD. Then, the Fuzzy Best–Worst Method (FBWM) is applied to calculate the weight of the criteria/sub-criteria. Finally, alternatives are ranked based on a combination of the Markov transition matrix and FBWM. The framework of this research is depicted in Fig. 1. The main advantages of this paper over the previous studies are as follows: (i) the simultaneous consideration of three important concepts namely sustainability, resilience, and customers' preferences in the SSP that never focused in the previous papers, (ii) developing a decision-making framework based on the Markov chain, QFD, and FBWM to benefit from their advantages concurrently. This combination was never performed in the previous researches in the SSP area. (iii) investigating the online marketplace as a case study that has been rarely addressed by the previous studies. The main research questions which this research answer are as follows:

- What are the main criteria/sub-criteria of the customer-based CSRSSP?
- Which criteria are the most influential ones in this research?
- How the feasible alternatives could be prioritized using Markovian-based FBWM?

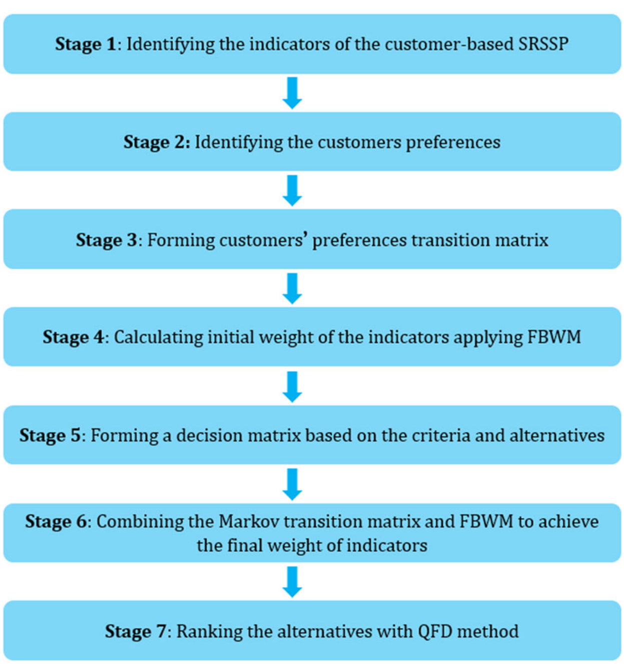

Fig. 1 The research framework

The rest of this research is structured as follows: Sect. 2 presents the literature review. The problem definition and the decision tree are provided in Sect. 3. The methodology of research is described in Sect. 4. Section 5 presents the computational results. Managerial implications and discussions are suggested in Sect. 6. Eventually, conclusions and future studies are given in Sect. 7.

2 Literature review

The importance of the SCM problem led to conducting several works in the recent years (for example see (De and Mahata 2020, 2021; Bhattacharya and De 2021; Bhattacharya and De 2021; De and Mahata 2021; Mamashli et al. 2021; Nayeri et al. 2021; Sazvar et al. 2021)). Supplier selection problem is a common problem which researchers investigated that especially in the last decade. Since it is necessary to select the suppliers first based on customer preferences when considering sustainable aspects, customer-based sustainable supplier selection is more important. However, disruption in this problem is available and should not ignore that disruption and uncertainty are an inseparable part of this problem in reality. In addition, the criteria for this selection process may change in long term and some ideas should involve through the Markov chain transition matrix for the next periods. So, a customer-based sustainable resilient supplier selection problem using the Markov chain will be investigated in the current study. Furthermore, this study includes three research streams. First, the sustainable supplier selection, resilient one, and finally the combined sustainable and resilient dimensions in supplier selection problem with more focus on combining the customer preferences.

2.1 Sustainable supplier selection

In the sustainable supplier selection stream, Tavana et al. (2017) used an integrated framework based on ANP and QFD for the sustainable supplier selection problem. They considered customer requirements using QFD as criteria and ranked them with ANP. Finally, suppliers were ranked with multi-objective optimization based on ratio analysis and weighted aggregated sum product assessment. Only in their study, customer-based dimension for supplier selection was considered. However, Fallahpour et al. (2017) gathered criteria and sub-criteria of sustainable supplier selection through a questionnaire-based survey. They used fuzzy preference programming and Fuzzy TOPSIS for selecting the best supplier with uncertainty. Jain and Singh (2020) proposed a two-phase decision model using the Fuzzy Interference System (FIS) along with Fuzzy Kano Philosophy for the sustainable environment for selecting sustainable suppliers. Tirkolaee et al. (2020) first used Fuzzy ANP for ranking criteria and sub-criteria and then fuzzy DEMATEL for relationships identification and finally, Fuzzy TOPSIS to prioritizing suppliers for the sustainable-reliable supplier selection problem with GAMS/CPLEX solver. Stević et al. (2020) investigated sustainable supplier selection for a polyclinic using a new method of MCDM techniques named Measurement of Alternatives and Ranking according to Compromise Solution (MARCOS). They considered 21 criteria related to the sustainability dimension and selected the best supplier. Mahmoudi et al. (2020) focused on supplier selection based on a sustainability framework for megaprojects. They used the Ordinal Priority Approach (OPA) and grey system theory for considering uncertainty. Chen et al. (2020) developed an integrated rough-fuzzy approach for sustainable supplier selection. They used DEMATEL for weighting the related criteria and TOPSIS for supplier prioritization. They used the fuzzy set for the supply chain internal uncertainties and a rough set for external uncertainties. Hendiani et al. (2020) proposed a sustainable supplier selection approach based on likelihood-based MCDM. In their study, the criteria weights were calculated based on interval type-2 trapezoidal fuzzy sets. Finally, some real cases were investigated based on their proposed approach and compared with other MCDM methods outputs for supplier ranking. Recently, Chia-Nan et al. (2022) also proposed a model for sustainable supplier selection especially based on the situations caused by COVID-19 outbreak. They used Fuzzy Analytical Hierarchy Process (FAHP) model and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) for supplier evaluation based on sustainability metrics for a manufacturing company in Vietnam as the case study. Thanh and Lan (2022) developed a model for sustainable supplier selection for a food company. They first defined several criteria and weighted then using FAHP and then proposed a Combined Compromise Solution for supplier selection decision making. Tong et al. (2022) proposed a framework for sustainable supplier selection using improved PROMETHEE technique especially for small and medium-sized enterprises. Their results showed that beside cost, two other criteria are very important in supplier selection problem which were credit and irregularity. (Van Thanh and Lan 2022) used multi-criteria decision-making methods include FAHP and CoCoSo solution algorithm to evaluate sustainable supplier in a food processing company. The suppliers' evaluation indicators were in three dimensions include economic, environmental, and social dimensions. Based on their findings, the most important indicators include product quality, employee empowerment, and production cost. (Shao et al. 2022) presented a model for evaluating and allocating orders for sustainable supplier selection under conditions of uncertainty in the COVID-19 pandemic era. The suppliers' evaluation indices were weighted by the entropy method, and then the suppliers were prioritized by the TOPSIS method. The most important indicators of their study are product quality, delivery speed and dealing with demand changes. Then, using the developed NSGA-II algorithm, the order allocation model has been solved. (Chai et al. 2023) evaluated and selected a sustainable supplier using intuitionistic and interval-valued fuzzy MCDM approach. In order to deal with the errors of human opinions, they used new fuzzy approaches that increase the accuracy of experts' answers. Their presented method has been used to evaluate e-bike suppliers, whose most important indicators identified in their study include economic capability, risk management, job creation, and waste management. (GHOSH et al. 2023) in a study evaluated and selected a green supplier in the automotive industry. They selected 14 indicators to evaluate suppliers, which were weighted by the principal component analysis (PCA) method. Their findings showed that the indicators include cooperation with suppliers for green purchasing, green design in especially resources consumption, and environmental planning are the most important indicators. Then, using SAW method, the suppliers were also ranked in their study.

2.2 Resilient supplier selection

In the second stream, in addition to sustainable supplier selection, many papers focused only on resilient supplier selection. Pramanik et al. (2017) developed an integration framework for a resilient supplier selection problem. They collected the criteria of resilient suppliers with the use of QFD and ranked them via AHP. Then they used TOPSIS to prioritize suppliers. So, customer preferences were focused on their study. Parkouhi and Ghadikolaei (2017) determined the effective elements in resilient supplier selection with the Analytic Network Process and then calculated each resilience level through the grey VIKOR method. Finally, the most resilient supplier was selected. Davoudabadi et al. (2019) first gathered criteria for the resilient supplier selection problem from decision-makers and changed them into interval-value intuitionistic fuzzy numbers and ranked them based on the entropy index.

Subsequently, they used a complex proportional assessment method for ranking the suppliers. Gan et al. (2019) also investigated resilient supplier selection based on Fuzzy BWM and GMO-RTOPSIS. They calculated the weight of decision-makers by the Best–Worst Method and then the best resilient supplier selected via GMO-RTOPSIS. Parkouhi et al. (2019) considered resilient supplier selection using the Grey DEMATEL technique for determining the importance level of criteria and the suppliers were ranked with the use of grey simple additive weighting technique. Hasan et al. (2020) developed a Fuzzy Multi-Attribute Decision Making (F-MADM) for the resilient supplier selection problem in logistic 4.0. in this environment, they developed a Decision Support System (DSS) for facing the imprecise data. Then, the suppliers were ranked using Fuzzy TOPSIS, and these scores transfer to an order allocation mathematical model as input. Finally, a sensitivity analysis for the trading of between supplier's cost and resilience index was done. Sureeyatanapas et al. (2020) focused on resilient supplier selection for a computer hardware components company. They considered the resilient criteria and scored them by using evidence theory for considering uncertainty. Then the TOPSIS method was used for ranking the case study suppliers. Waleekhajornlert and Sureeyatanapas (2020) focused on the resilient supplier selection problem. They defined resilient-based criteria for electronic company suppliers and used extended TOPSIS for ranking the suppliers. Leong et al. (2022) focused on resilience dimension while tried to select the best supplier for a food manufacturing company as a case study. They first considered some resilient criteria such as flexibility and responsiveness beside other important criteria including cost, quality, and delivery time. Then they used a combined GRA-BWM-TOPSIS for supplier selection while used GRA for defining the importance score of each criterion, BWM for calculating the criteria weights, and finally, TOPSIS for potential suppliers ranking.

2.3 Sustainable-Resilient supplier selection

Recently, there is a growing interest in studying sustainable and resilient dimensions simultaneously in the last years. In this stream, Amindoust (2018) considered the supplier selection problem when resilience and sustainability approaches are focused on disruption situations. In this study, for calculating indices of supplier selection, a modular Fuzzy Inference System is used. Besides, the assurance Region DEA method was used to rank the suppliers. Vahidi et al. (2018) also proposed a model that considered sustainable supplier selection under operational and disruption risks. They chose sustainability criteria via SWOT- QFD framework. And then the objective functions are defined for mixed sustainability-resilience in a case study. The authors applied an integrated SWOT-QFD method to determine the most influential sustainability criteria related to the manufacturer's strategies. Cheraghalipour and Farsad (2018) developed a MILP model for the sustainable supplier selection model with disruption risks for minimizing cost and maximize sustainability score. They used BWM for ranking criteria and potential supplier too. Kaur et al. (2018) proposed supplier selection MILP and MINLP models considering sustainability and uncertainty for a resilient supply chain. Mohammed et al. (2018) evaluated suppliers with respect to their traditional, green and resilience characteristics. AHP technique is used for ranking relevant criteria and Fuzzy TOPSIS for ranking suppliers. In addition, Alikhani et al. (2019) investigated sustainable supplier selection by considering risks. They used an extended super-efficiency DEA model to cover both sustainability and risk factors and ranked the suppliers. Zekhnini et al. (2020) proposed an intelligent decision-making model for resilient-sustainable-smart supplier selection. They pointed out that suppliers should improve their competitiveness based on the dimensions mentioned. They finally used an adaptive fuzzy neuro network for supplier ranking. Zavala-Alcívar et al. (2020) assessed the sustainable and resilient suppliers for Agri-food supply chains. They used artificial intelligence for supplier evaluation based on the input criteria. Fallahpour et al. (2021) developed a hybrid decision-making framework to investigate the sustainable-resilient SSP. The authors combined the decision-making and artificial intelligence methods to measure the weights of the indicators and performance of the suppliers. It should be noted that they selected the palm oil industry as a case study. Fazlollahtabar and Kazemitash (2021) conducted a study in the field of the sustainable-resilient SSP. In this regard, at the outset, the authors identified the related indicators and alternatives, and then developed a novel method named Fazl-Tash to measure the importance of the criteria. Shao et al. (2022) tried to develop a model for supplier selection and order allocation based on sustainability while considered the supply disruptions caused by COVID-19 outbreak. So, they used a multi-stage multi-objective optimization model and also a novel nRa-NSGA-II algorithm in order to first select the best supplier and then assign the order to that. Tao et al. (2022) focused on product life cycle cost model for a sustainable-resilient supplier selection problem. They developed a multi-objective linear programming model for sustainable resilient supplier selection in which there were three objective functions such as minimizing product life cycle cost, maximizing sustainability and resilience in order to select the best supplier. They used goal programming for solving their model in a Taiwanese LED company. Hosseini et al. (2022) also focused on sustainable supplier selection and order allocation while demand and supplier grading uncertainty in order to cover resilience dimension in their proposed supplier selection problem. They first defined several criteria in sustainability and resilience dimensions and weighted them using Best–Worst Method (BWM). Then, they developed a mathematical model for supplier selection while tried to maximize sustainability and minimize the costs. They considered the uncertainties parameters in the model subjections and solved their model based on a real case study. Afrasiabi et al. (2022) suggested a hybrid model based on MCDM techniques for sustainable and resilient supplier selection. They tried to consider the uncertainties and disruptions may occur during COVID-19 pandemic. So, they weighted the criteria using FBWM, and then ranked the potential suppliers based on TOPSIS in a gray environment. (Rostami et al. 2023) have presented a study on the topic of sustainable supply chain evaluation. In their study, it has been pointed out that during the COVID-19 pandemic, attention to resilience criteria has become important again, and combined with sustainable supply chain, they have evaluated medical equipment suppliers. In their study, suppliers were evaluated according to the four dimensions of lean, agility, resilience, sustainability, and digitalization, and the most important indicators identified include cost, reliability, and environmental control. They used GP-based BWM for criteria evaluation.

Khan et al. (2023) evaluated and selected suppliers in a resilient and sustainable approach. In their study, first, using the SCOR 4.0 approach, they analyzed supplier relationships and the needs of each sector, and the desired components were weighted using the BWM method. The most important indicators identified include accuracy, on-time delivery, distribution quality, and material cost. Then, the suppliers were evaluated using the gradient boosting algorithm.

2.4 Customer-based supplier selection

With knowledge of customer needs importance in supplier selection decision making, only a few papers considered customer-oriented supplier selection. For example, Asadabadi (2017) combined Markov chains for customer needs changings and ANP and QFD connects it with product requirements and the best supplier was selected. (Sahu et al. 2022) presented a new decision-making framework for supplier selection according to lean, agility, resilience, and green criteria. LARG criteria simultaneously ensure environmental balance, customer satisfaction, supply chain relevance, effectiveness, and sustainability. The method presented in their study was a combination of DEMATEL and AHP for weighting indicators, and then Extended MOORA and SAW methods were used to evaluate suppliers. In their study, 63 criteria were considered to evaluate suppliers, the most important criteria include agility in internal processes, production flexibility, online customer communication processes, and demand- supply change management. Table 1 categorizes some of the important related papers.

2.5 Research gaps and contributions

By reviewing the research literature, As can be seen in Table 1, it can be seen that no studies have been found that have simultaneously included the topic of resilience and sustainability by considering customer preferences in the issue of supplier evaluation and selection. So, customer preferences have been rarely addressed by previous papers in the SSP literature while this issue is one of the most important challenges in SCM and it can affect the decision-making process. Therefore, in general, SRSSP has thematic novelty by considering the components of customer preferences and satisfaction. In this study, the dimensions of sustainability, resilience, considering the customers' preferences in dimensions evaluation, will be considered simultaneously. On the other hand, the solution method used in this study has not been found in any other study. A study that evaluates suppliers by combining QDF method and Markov chain with FBWM method has not been found in previous studies. Therefore, to cover the mentioned gaps, the current work developed a decision-making framework based on the Markov-chain method, QFD approach, and FBWM to investigate the customer-based sustainable-resilient SSP. In terms of a case study, it can be mentioned that this study, unlike other studies, deals with the selection of a supplier in an online marketplace, which has not been noticed by researchers before. Based on the above discussion, the main contributions of this research are as follows:

(1) This research is the first one that investigates customer-based sustainable-resilient supplier selection problem under the fuzzy environment.
(2) This research develops an integrated approach based on the Markov-chain, QFD, and FBWM methods. To the best of our knowledge, this is the first application of this method (integrated Markov chain-QFD-FBWM) in the supplier selection area that able the decision-makers to benefit advantages of these methods concurrently.
(3) This study investigates the online marketplace as a case study which was not focused before for supplier selection problem.

Table 1 Categorizing related papers

Paper	Resilient	Sustainable	customers' preferences	Methodology
(Pramanik et al. 2017)	×		×	AHP-TOPSIS-QFD under fuzzy environment
(Parkouhi and Ghadikolaei 2017)	×			Fuzzy ANP and grey VIKOR
(Asadabadi 2017)			×	Markovian-based ANP and QFD
(Fallahpour et al. 2017)		×		Fuzzy preference programming and Fuzzy TOPSIS
(Pramanik et al. 2017)	×			Fuzzy TOPSIS
Kaur et al. (2018)	×	×		Fuzzy MCDM, MILP and MILNP
(Mohammed et al. 2018)	×	Green		AHP and Fuzzy TOPSIS
(Alikhani et al. 2019)	Risk	×		Super-efficiency DEA
(Cheraghalipour and Farsad 2018)	Risk	×		MILP and BWM
(Amindoust 2018)	×	×		Modular Fuzzy Inference System and DEA
(Vahidi et al. 2018)	×	×		SWOT- QFD
(Davoudabadi et al. 2019)	×			Complex Proportional Assessment (COPRAS)
(Gan et al. 2019)	×			Fuzzy BWM and GMO-RTOPSIS
(Parkouhi et al. 2019)	×			Grey DEMATEL and Grey SAW
(Jain et al. 2020)		×		Fuzzy Kano & FIS
(Hendiani et al. 2020)		×		Likelihood-based MCDM
(Waleekhajornlert and Sureeyatanapas 2020b)	×			TOPSIS
Tirkolaee et al. (2020)		×		Fuzzy ANP-DEMATEL and TOPSIS
(Zekhnini et al. 2020)	×	×		Adaptive fuzzy neuro network
(Zavala-Alcívar et al. 2020)	×	×		Artificial intelligence
Fallahpour et al. (2021)	×	×		Fuzzy MCDM + Artificial intelligence
Fazlollahtabar and Kazemitash (2021)	×	×		Fazl-Tash method
Hosseini et al. (2022)	×	×		BWM and mathematical model
Afrasiabi et al. (2022)	×	×		FBWM and TOPSIS
Leong et al. (2022)	×			Combined GRA-BWM-TOPSIS
(Sahu et al. 2022)	×	Green	agile	DEMATEL—AHP—Extended MOORA—SAW
(Van Thanh and Lan 2022)		×		FAHP—CoCoSo
(Shao et al. 2022)	×	×		Entropy—Topsis—NSGA-II
(Chai et al. 2023)		×		Intuitionistic and interval-valued fuzzy MCDM approach
(GHOSH et al. 2023)		Green		PCA & SAW
(Khan et al. 2023)	×	×		BWM—gradient boosting algorithm
(Rostami et al. 2023)	×	×		Goal Programming-based BWM
(Sharma and Joshi 2023)			×	WASPAS-SWARA
(Sathyan et al. 2023)			×	FDEMATEL-FAHP-FTOPSIS
This study	×	×	×	QFD-Markovian-Based Fuzzy BWM

3 Problem definition

3.1 Case study

The proposed decision-making framework has been implemented in an online marketplace in Iran. This company sells several categories of products such as furniture, electronics, shoes, clothes, books, and toys. Online market places are useful and interesting for customers especially in some situation such as being far from other markets, elderly people, and also during pandemics like the situation that coronavirus is caused recently. In this situation in order to avoid going to stores physically, where there is more need for social distance to minimize the risk of infection, clients will prefer to buy their requirements from online marketplaces. As more consumers turn to online shopping to buy everyday needs, orders of customers in online market places have also increased. However, the

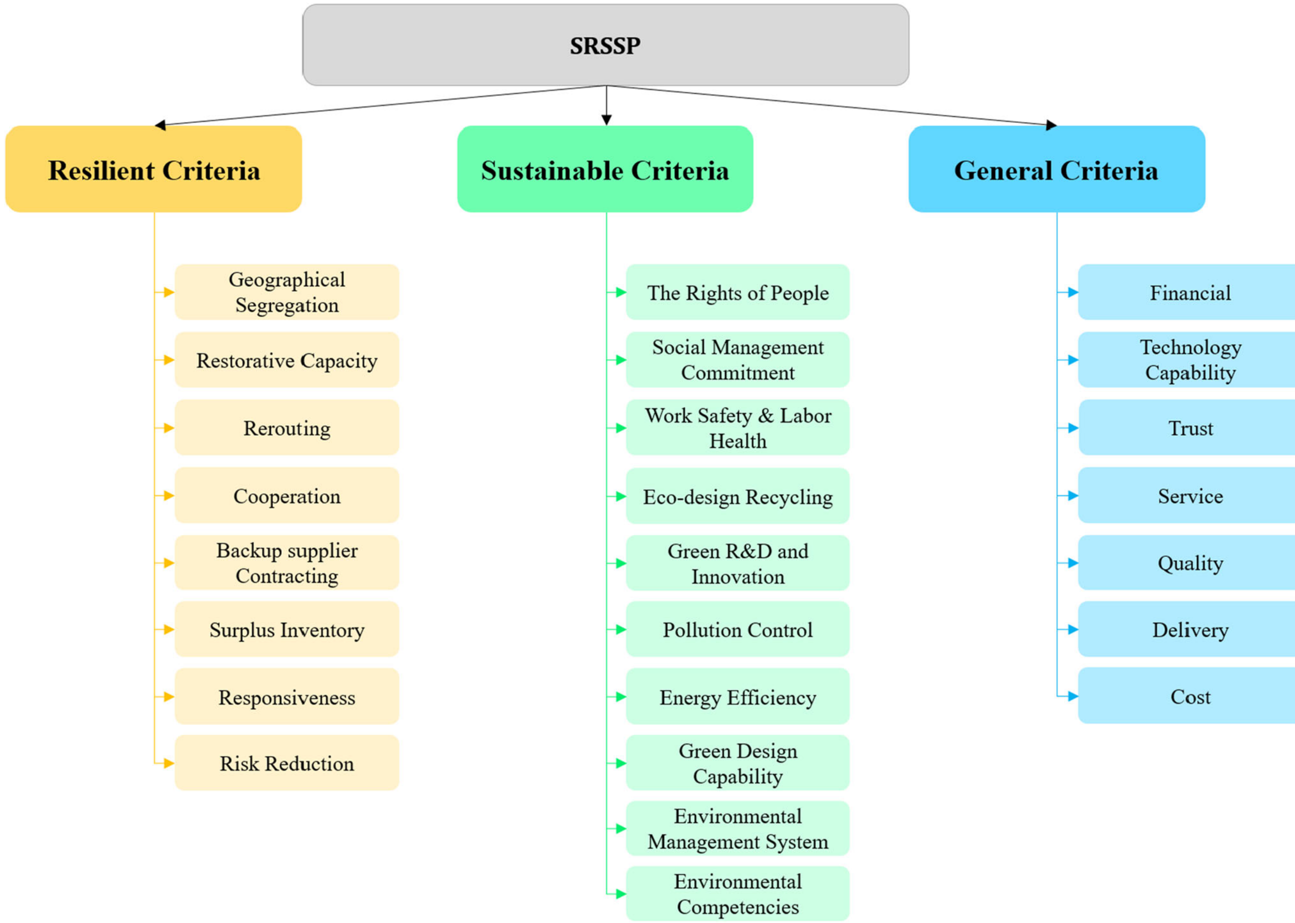

Fig. 2 The decision tree of this research

concern is to maximize responding to demands due to the best decision makings. The question now seems to be whether companies can adapt and how to supply customer demands and needs. The case study, obtain the products from different suppliers, and in every period of time needs to select the best based on customer needs, requirements, and criteria.

3.2 Propose decision tree

This section is dedicated to describe the research problem and to depict the decision tree. As mentioned before, there are several potential suppliers and the case study managers wants to select the best suppliers among them based on sustainability criteria, resilience criteria, and finally general ones based on its customers point of view. For each of these dimensions, some sub-criteria are defined. General measures are consisting of the criteria such as cost, quality, and delivery which are essential elements of traditional SSP. Sustainable measures are involving criteria which are related to the environmental impact and social responsibility, like green design capability, work safety, and labor health. Also, resilient measures are including criteria which are relevant to the ability to return to equilibrium. Based on the above definition and the literature, the complete decision tree of this research is illustrated in Fig. 2. It should be noted that the decision tree is depicted based on some related papers like (Fallahpour et al. 2017; Amindoust 2018) and also the experts are experienced more than five years who are responsible for the supply unit in some online markets. The description of each sub-criterion is provided in Appendix A. The strategy of the case study company is selecting suppliers considering a dynamic environment that means they want to consider the changing priorities of customer needs. In other words, the company wants to perform customer-based supplier selection approach. In the literature, some factors introduced for priorities of customer like performance, reliability, and price, while their weights may change during the different periods for the customers. For incorporating this issue in the problem, we employ the Markov chain (transition matrix) for calculating the probability of transition of the customer priority from one factor to another.

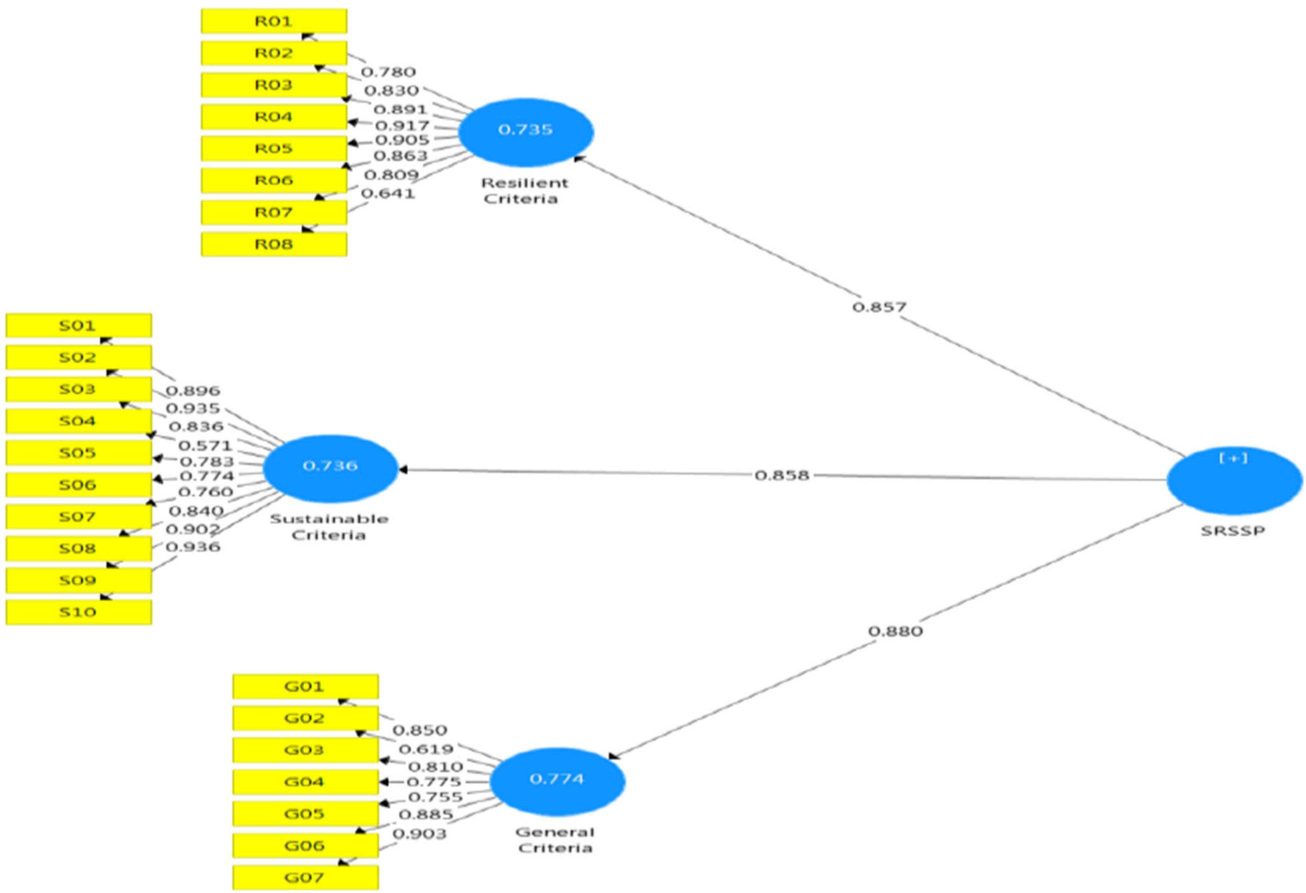

Fig. 3 Smart-PLS output model for the proposed decision tree

For evaluating the validation of all parts of the decision tree includes the main dimensions (Sustainability, Resilience, and General) and also the sub-criteria related to each dimension, "SmartPLS" software is used. As shown in Fig. 3, the relationship strength between each factor with its related criteria calculated in factor load metric. This metric shows whether if a criterion is valid enough for its related dimension based on expert opinion, the factor load value is between zero and one. There is a weak relation if this value is less than 0.3, an acceptable relation if it is between 0.3 and 0.6, and finally, strong relation if it is greater than 0.6 (Silaparasetti et al. 2017). Five people, online market supply managers, answered the validity questionnaire. So, Fig. 3 is depicted the factor load of all criteria and sub-criteria based on the expert answers. Cronbach's alpha coefficients are important to accept the decision tree components. These values are shown in Appendix B which are calculated based on the expert answers by which the decision tree model validity is been approved. As can be seen in Appendix B, all sub-criteria have strong relations with their related dimension except one of them (i.e., eco-design recycling) which has medium but acceptable relation with sustainability dimension. Finally, the whole decision tree is validated based on Cronbach's alpha coefficients.

4 Methodology

In this section, the methodology of the current research is presented. This research applies the combination of QFD, Markov chain, and FBWM to investigate the SRSSP. In the following, we define these approaches in detail.

4.1 Markov Chains and QFD

Quality Function Deployment (QFD) proposed first in 1970s, as a tool for considering the stakeholder requirements and transforming to quality characteristics. One of the important part of QFD consists of extract requirements of customers in an organization and weight them (Abdel-Basset et al. 2018). It means that for defining states of the system, QFD is used due to identify customer needs and requirements as states. QFD has many advantages, including reducing the number of changes in designing plans, reducing the initial costs of introducing the product to the market, customer orientation, reducing customer complaints about the product, and increasing customer satisfaction in meeting their needs and wants. QFD steps include: (1) identify quality requirements (WHATs) or needs, (2) calculating weights of WHATs, (3) identify criteria, or quality characteristics (HOWs), (4) construct the relationship matrix between WHATs and HOWs. (5) determine the list of competitors and finally, (6) calculate the scores of available suppliers. Since using QFD application with Markov chain approach can be useful in supplier selection problem (Asadabadi 2017a), in second step of QFD, Markov chain is used for matrix of transition probabilities that can consider changes in customer needs with the aim of covering resilience characteristics. Markov chain has previously been applied in other studies for tracing and patterning customer needs over a while. There are some advantages when QFD and Markov chain integrated for Voice-of-Customers. In other words, a deep understanding of customer needs and requirements takes place through QFD while the Markov chain completes this understanding when considering the customer needs both now and also in the future. So, the customer preferences today can be updated through the Markov chain and different decisions make base on the long-term changes of customer ideas. For example, for designing new products, Markov chain prediction can help a company to design the products more compatible with today's customer needs. In other words, it makes sense that there is a stronger relationship between the design group and customers (Gotzamani et al. 2018). An integrated method of QFD and Markov chain consists of the following steps (Asadabadi 2017a):

4.1.1 Identify customer needs and quality requirements (WHATs) and their initial priorities

For identifying the customer needs, we used posts aimed at getting customers' opinions on social networks of the studied online store, where customers mentioned their needs and even complaints. Also, in the Customer Relationship Management (CRM) office of the case study, there is the Voice of Customers (VOC), so, some voices were also discussed in addition to reviewing customers comments. Based on this, the number of 1000 customer comments in targeted shared posts and the number of 200 customer voices were reviewed in the last six months, and among these, the needs and requirements based on the frequency of repeating them with the presence of experts and managers were finalized and summarized. Then, suppose that ranking customer needs also is done via managers and decision-makers or using MCDM methods. So that initial list of customer needs with their normalized weights at time zero (the initial time) is presented in the matrix W_{need} as Relation (1).

$$W_{\text{need}} = \begin{bmatrix} Wn_1 \\ Wn_2 \\ \vdots \\ Wn_n \end{bmatrix} \tag{1}$$

Assume that at the initial time Wn_1 is greater than Wn_2 and it means that customer preference for n_1 is more than n_2. But in next the period of time, we are not sure that the priority will remain like this and it will change. The time interval depends on consuming patterns, product characteristics and etc.

4.1.2 Transition matrix

Discrete times, the customer needs will change and not be always in just one special state, and also different weights can be occurred. In this situation, the Markov chain is useful to model these dynamic changes within periods of time. Interval time can be defined as day, week, month, and year based on product characteristics. Set of states defined as customer needs: S = $\{n_1 . n_2 \ldots . n_n\}$. Also set of time considered is T = $\{t_0 . t_1 \ldots . t_m\}$. p_{ij} is the probability of moving from ith state to jth that is changing from Wn_i toWn_j.

The one-step transition matrix is shown in the matrix P as Relation (2).

$$P = \begin{bmatrix} p_{11} & \cdots & p_{1n} \\ \vdots & \ddots & \vdots \\ p_{n1} & \cdots & p_{nn} \end{bmatrix} \tag{2}$$

For computing p_{ij}, we can use data from the organization for example from its Information Communication Technologies (ICT) Systems or decision-makers and experts. Furthermore, first, assume that there are c_{ik} customers who prefer n_i types of requirements at k^{th} period and b_{ijk} customers are willing to transfer from n_i to n_j at next period of time. So that the probability of y_{ijk} is as Relation (3).

$$y_{ijk} = \frac{b_{ijk}}{c_{ik}} \tag{3}$$

If after a sequence of periods, p_{ijk} can be estimated with y_{ijk} considering the following condition in Relation (4).

$$\left| y_{ijk} - p_{ijk} \right| \le \varepsilon \tag{4}$$

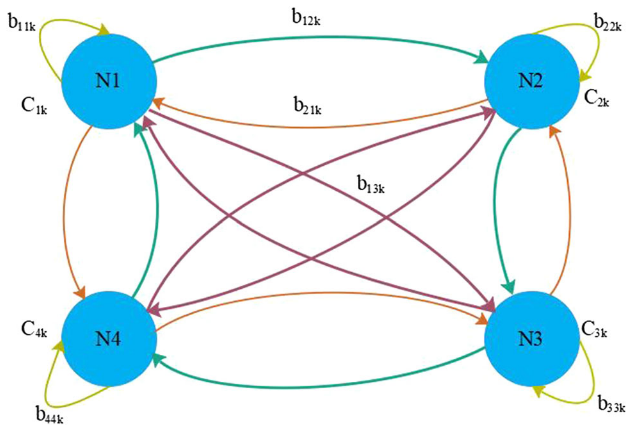

Fig. 4 Transition between states at *k*th period

Transition between states at *k*th period is shown in Fig. 4.

Now, the matrix for changing probabilities between different stages after k period is calculated as in the matrix P^k. This matrix is in fact, multiplying matrix P, k times consequently as Relation (5).

$$P^k = \begin{bmatrix} p_{11}^k & \cdots & p_{1n}^k \\ \vdots & \ddots & \vdots \\ p_{n1}^k & \cdots & p_{nn}^k \end{bmatrix} \tag{5}$$

4.1.3 Customer Needs or quality requirements final weights

Now, by frequently multiplying matrix W_{need} in transition matrix P^k in different k the weights of customer needs will calculate in k^{th} period after the initial time as Relation (6).

$$W_{\text{need}}{}^{(k)^T} = W_{\text{need}}{}^{(0)^T} P^{(k)} \tag{6}$$

After some periods, $W_{\text{need}}{}^{(k)^T}$ convergences to a unique matrix and no obvious difference will occur. This matrix shows W^*_{need}. Markov chain cannot make decision lonely but helps and enables another MCDM method that is Fuzzy BWM to rank the suppliers considering the obtained pattern.

4.1.4 Identify criteria or quality characteristics (HOWs)

In this step, it is necessary that gather some criteria or quality characteristics which are important in the main aim of the problem and also customer view. These criteria will be as same as the criteria and sub-criteria defined in Sect. 3.2 as proposed decision tree.

4.1.5 Construct the relationship matrix between WHATs and HOWs and calculating weights of HOWs

Then, every criterion is compared with respect to each need. These weights build the matrix $W_{\text{need}-\text{criteria}}$ as Relation (7).

$$W_{need-Criteria} = \begin{array}{c} \\ n_1 \\ n_2 \\ \vdots \\ n_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \end{array} \\ \begin{bmatrix} W_{11} & W_{12} & \cdots & W_{1n} \\ W_{21} & & \ddots & W_{2n} \\ \vdots & & & \vdots \\ W_{n1} & & \cdots & W_{nn} \end{bmatrix} \end{array} \tag{7}$$

The final weights of the criteria which considering their relationship with Needs is calculated as Relation (8).

$$W_{\text{Fcriteria}=} W^*_{\text{need}} * W_{\text{need}-\text{criteria}} \tag{8}$$

For calculating the weights that show the relation between needs and criteria, FBWM is used that explained in the next section.

4.2 FBWM

Using exact values in the decision-making process is one of the problematic points. Because some criteria are difficult to measure with crisp values and they are usually ignored during evaluation. Another problem is that mathematical models are built on exact values. These methods cannot deal with the ambiguities, uncertainties, and vagueness of decision makers that cannot be expressed in clear quantities. Decisions to be made in complex contexts, usually characterized by multiple aspects of evaluation. They are typically affected by uncertainty, which stems from the insufficient or inaccurate nature of the input data as well as the subjective preferences and evaluations of the decision maker. Using fuzzy set theory allows us to incorporate unquantifiable, incomplete, unobtainable, and somewhat uninformed facts into the decision-making model. Applications of fuzzy sets in the field of decision-making, in most cases, have included "fuzzification" of classical decision-making theories. Fuzzy sets have powerful properties that should be included in many optimization techniques which Multi-criteria Decision Making (MCDM) is one of these cases. Fuzzy logic provides a useful method to reduce the error in MCDM problems. Because in multi-criteria decision-making problems, often the data are inaccurate and ambiguous. In real-world decision-making situations, the use of classical multi-criteria decision-making methods may face serious limitations in practice. Because the criteria are inherently inaccurate or vague in their information. Among fuzzy MCDM, methods, FBWM is one of the popular methods to investigate decision-making problems (Mi and Liao 2019). This method has many advantages compared to similar approaches (like AHP) which these are led to increase reliability and compatibility of the results. The main advantages of FBWM are (1) structured pairwise comparison, (2) less requirement for data, and (3) high reliability due to not considering all comparison vectors and only two of them (Rezaei et al. 2016; Aria et al. 2020). In other words, when the number of criteria/sub-criteria is high, using FBWM leads to reducing the cognitive burden and also increasing the reliability of the outputs. It is supposed that the readers are familiar with basic fuzzy concepts. For this reason, we avoid presenting the fuzzy concepts in this section. Let $\widetilde{a} = (l, m, u)$ denotes a triangular fuzzy number. The Graded Mean Integration Representation (GMIR), showed by $R(\widetilde{a})$, is defined using Relation (9) below:

$$R(\widetilde{a}) = \frac{l + 4m + u}{6} \tag{9}$$

The steps of FBWM are as follows (Guo and Zhao 2017):

Step 1: In the first step, decision-makers determine the worst and the best indicators.

Step 2: Here, the comparison between the best indicator and other ones, and also other criteria with the worst one is done. In order to form the comparison vectors, the following transformation in Table 2 can be used.

Suppose that "W" and "B" denote the worst and the best criteria, respectively. Also, $\tilde{A}_W = (\tilde{a}_{1W}, \tilde{a}_{2W}, \ldots, \tilde{a}_{nW})$ and $\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2}, \ldots, \tilde{a}_{Bn})$ show the comparison vectors of other-to-worst and Best-to-other, respectively. It should be noted that $\widetilde{a}_{BB} = \widetilde{a}_{WW} = (1, 1, 1)$.

Step 3: Calculating the optimal weights. Let $\widetilde{w}_j = (l_j^w, m_j^w, u_j^w)$, $\widetilde{a}_{jW} = (l_{jW}, m_{jW}, u_{jW})$, $\widetilde{a}_{jW} = (l_{jW}, m_{jW}, u_{jW})$ and $\widetilde{\xi}^* = (k^*, k^*, k^*)$. The FBWM is determined the optimal weight of the criteria/sub-criteria using the non-linear model as Relation (10)

Table 2 Transformation table of linguistic variables (You et al. 2017a, b)

Linguistic terms	Membership function
Equally important (EI)	(1, 1, 1)
Weakly important (WI)	(0.667, 1, 1.5)
Fairly important (FI)	(1.5, 2, 2.5)
Very important (VI)	(2.5, 3, 3.5)
Absolutely important (AI)	(3.5, 4, 4.5)

$$\min \widetilde{\xi}^*$$
$$s.t. \begin{cases} \left| \dfrac{(l_B^w, m_B^w, u_B^w)}{(l_j^w, m_j^w, u_j^w)} - (l_{Bj}, m_{Bj}, u_{Bj}) \right| \leq (k^*, k^*, k^*)\ \forall j \\ \left| \dfrac{(l_j^w, m_j^w, u_j^w)}{(l_W^w, m_W^w, u_W^w)} - (l_{jW}, m_{jW}, u_{jW}) \right| \leq (k^*, k^*, k^*)\ \forall j \\ \sum_{j=1}^{n} R(\tilde{w}_j) = 1 \quad \forall j \\ l_j^w \leq m_j^w \leq u_j^w \quad \forall j \\ l_j^w \geq 0 \quad \forall j \end{cases} \tag{10}$$

Step 4: After solving the model (10) and determining the optimal weights, to examine the reliability and compatibility of the results, the Consistency Ratio (CR) must be checked. At first, based on the comparison vector of best-to-worst criteria, the Consistency Index (CI) is determined (according to Table 3). Then, the consistency ratio calculated applying the following formula as Relation (11) (Guo and Zhao 2017):

$$\mathrm{CR} = \frac{\xi^*}{\mathrm{CI}} \tag{11}$$

The smaller value for CR (close to zero) is better.

4.3 Determine list of competitors Calculate the scores of available suppliers

Criteria values of all suppliers are normalized in an evaluation matrix which has shown in the matrix $W_{\text{supplier-criteria}}$ as Relation (12), where s_i represents the suppliers and c_i also represents the criteria.

$$W_{supplier-Criteria} = \begin{array}{c} \\ s_1 \\ s_2 \\ \vdots \\ s_n \end{array} \begin{array}{c} \begin{array}{cccc} c_1 & c_2 & \cdots & c_n \end{array} \\ \begin{bmatrix} u_{11} & u_{12} & \cdots & u_{1n} \\ u_{21} & & \ddots & u_{2n} \\ \vdots & & & \vdots \\ u_{n1} & & \cdots & u_{nn} \end{bmatrix} \end{array} \tag{12}$$

As u_{ij} is in normalized form, it is calculated when the real number normalized using Relation (13). It should be noted that in calculating the normalized scores of each supplier, considering that all the criteria are not aligned, the evaluation scores are calculated by considering this disparity. For example, the supplier who had the lowest cost (criterion in the negative direction) has the highest evaluation score, as well as in the pollution control criterion

Table 3 Consistency Index (CI) based on (You et al. 2017b)

	(EI)	(WI)	(FI)	(VI)	(AI)
$\tilde{a}_{BW}$	(1, 1, 1)	(0.667, 1, 1.5)	(1.5, 2, 2.5)	(2.5, 3, 3.5)	(3.5, 4, 4.5)
CI	3.00	3.80	5.29	6.69	8.04

(criterion in the positive direction), the supplier who has a higher control has a higher score.

$$u_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \tag{13}$$

Finally, the ranking of the suppliers is calculated by Relation (14).

$$W_{\text{Fsupplier}} = W_{\text{supplier-criteria}} * W^{T}_{\text{Fcriteria}} \tag{14}$$

$$W_{\text{need}} = \begin{array}{c} \text{Performance} \\ \text{Availability} \\ \text{Reliability} \\ \text{Price} \\ \text{Serviceability} \end{array} \begin{bmatrix} 0.20 \\ 0.27 \\ 0.17 \\ 0.28 \\ 0.08 \end{bmatrix}$$

These weights are considered as a priority in the first period.

As mentioned previously, needs and requirements priority will change over time. The transition matrix P as discussed in Sect. 4.1.

$$P = \begin{array}{c} \\ \text{Performance} \\ \text{Availability} \\ \text{Reliability} \\ \text{Price} \\ \text{Serviceability} \end{array} \begin{bmatrix} \text{Performance} & \text{Availability} & \text{Reliability} & \text{Price} & \text{Serviceability} \\ 0.25 & 0.10 & 0.15 & 0.16 & 0.34 \\ 0.14 & 0.37 & 0.21 & 0.18 & 0.10 \\ 0.10 & 0.29 & 0.42 & 0.05 & 0.14 \\ 0.18 & 0.08 & 0.32 & 0.17 & 0.25 \\ 0.13 & 0.20 & 0.08 & 0.12 & 0.47 \end{bmatrix}$$

5 Computational results

5.1 QFD and Markov chain results

To determine the quality requirements and needs of customers (first step in *QFD*) who buy the product from this online market, an online questionnaire is performed to collect their answers. After analyzing the answers, we found out that the requirements for purchasing different products mentioned by customers are as follows:

- Performance
- Availability
- Reliability
- Price
- Serviceability

The second step in *QFD* is prioritizing the quality requirements and needs (What's). For this aim, a team of experts and also some loyal customers asked to compare these needs according to their importance. The weights for every requirement are shown in the matrix W_{need} using the Fuzzy Analytical Hierarchy Process (FAHP).

Based on matrixes W_{need} and P, the priority matrixes for the initial period and either the next periods are calculated.

$$W_{\text{need}}{}^{(0)^T} = W_{\text{need}}{}^{(0)^T} P^{(0)} = [0.165 \quad 0.207 \quad 0.254 \quad 0.146 \quad 0.226]$$

$$W_{\text{need}}{}^{(1)^T} = W_{\text{need}}{}^{(0)^T} P^{(1)} = [0.151 \quad 0.224 \quad 0.240 \quad 0.128 \quad 0.255]$$

$$W_{\text{need}}{}^{(2)^T} = W_{\text{need}}{}^{(0)^T} P^{(2)} = [0.149 \quad 0.229 \quad 0.232 \quad 0.129 \quad 0.259]$$

$$W^{(3)^T}_{\text{need}} = W^{(0)^T}_{\text{need}} P^{(3)} = [0.149 \quad 0.229 \quad 0.233 \quad 0.129 \quad 0.260]$$
$$i \geq 3$$

Furthermore, regardless of initial priority, limiting the priority matrix for customer needs and requirements is obtained as displayed below:

$$W^{*}_{\text{need}} = \begin{array}{c} \text{Performance} \\ \text{Availability} \\ \text{Reliability} \\ \text{Price} \\ \text{Serviceability} \end{array} \begin{bmatrix} 0.149 \\ 0.229 \\ 0.233 \\ 0.129 \\ 0.260 \end{bmatrix}$$

Table 4 The outputs of FBWM for the criteria based on performance measure

Criteria	Resilient	Sustainable	General
Optimal weights	0.3543872	0.2047449	0.4408679

$\xi^{*}= 0.3139305$ CI = 5.29 ➔ CR = $\frac{0.3139305}{5.29} = 0.05934$

5.2 FBWM results

This section presents the achieved outputs from the implementation of the FBWM for each customer preference. It should be noted that the pairwise comparison is a collection using questionnaires which are distributed between three groups of experts. The average opinions of three groups of experts are given in Tables 13,14, 15, 16, 17, 18, 19 and 20 in Appendix.

For performance measure, based on expert's opinions, general criteria are the best, and sustainable criteria are the worst. The achieved results are given in Table 4. The results of FBWM for resilient sub-criteria based on performance have been presented in Table 5. For this mode, experts select responsiveness as the best and geographical segregation as the worst criteria. Table 6 shows the outputs of FBWM for the indicators of the general dimension on the performance measure. In this mode, cost and trust are considered as the best and worst indicators. Also, the results of FBWM for sustainable criteria based on performance measures have been in Table 7, for this mode, social management commitment and green R&D and innovation are considered as the best and worst criteria, respectively.

The final weights of the sub-criteria (due to the weight of the criteria) are calculated in Table 8.

By applying a similar way, the final weights for criteria and sub-criteria are calculated for other measures

Table 5 The outputs of FBWM for the indicators of the resilient dimension based on performance measure

Sub-criteria	Risk reduction	Responsiveness	Surplus inventory	Backup supplier contracting	Cooperation	Rerouting	Restorative capacity	Geographical segregation
Optimal weights	0.1498368	0.2111796	0.1158378	0.1014194	0.09640289	0.1158378	0.1501135	0.05937212

$\xi^{*}= 0.7868032$ CI=8.04 ➔ CR = $\frac{0.7868032}{8.04} = 0.0978$

Table 6 The outputs of FBWM for the indicators of the general dimension based on performance measure

Sub-criteria	Cost	Delivery	Quality	Service	Trust	Technology capability	Financial
Optimal weights	0.2426258	0.1460281	0.1440970	0.1191124	0.06520699	0.1060301	0.1768997

$\xi^{*}= 0.77892$ CI=8.04 ➔ CR = $\frac{0.77892}{8.04} = 0.0967$

Table 7 The outputs of FBWM for the indicators of the sustainable dimension based on performance measure

Sub-criteria	Optimal weights	CR
Environmental competencies	0.1034598	$\xi^{*}= 0.598755$ CI=6.69 ➔ CR = $\frac{0.598755}{6.69} = 0.0895$
Environmental management system	0.1433557	
Green design capability	0.1039757	
Energy efficiency	0.09097389	
Pollution control	0.1017011	
Green R&D and innovation	0.04441177	
Eco-design recycling	0.1022407	
Work safety & labor health	0.09097389	
The rights of people	0.1279335	
Social management commitment	0.09097389	

Table 8 Final weights of the sub-criteria based on performance

Criteria	Criteria weight	Sub-criteria	Sub-criteria local weight	Final weight = Criteria weight × Sub-criteria local weight
General	0.4408679	Cost (1)	0.2426258	0.106965927
		Delivery (2)	0.1460281	0.064379102
		Quality (3)	0.144097	0.063527742
		Service (4)	0.1191124	0.052512834
		Trust (5)	0.06520699	0.028747669
		Technology Capability (6)	0.1060301	0.046745268
		Financial (7)	0.1768997	0.077989399
Sustainable	0.2047449	Environmental competencies (8)	0.1034598	0.021182866
		Environmental management system (9)	0.1433557	0.029351348
		Green Design Capability (10)	0.1039757	0.021288494
		Energy Efficiency (11)	0.09097389	0.01862644
		Pollution Control (12)	0.1017011	0.020822782
		Green R&D and Innovation (13)	0.04441177	0.009093083
		Eco-Design Recycling (14)	0.1022407	0.020933262
		Work Safety & Labor Health (15)	0.09097389	0.01862644
		The Rights of people (16)	0.1279335	0.026193732
		Social Management Commitment (17)	0.09097389	0.01862644
Resilient	0.3543872	Risk Reduction (18)	0.1498368	0.053100244
		Responsiveness (19)	0.2111796	0.074839347
		Surplus Inventory (20)	0.1158378	0.041051434
		Backup Supplier Contracting (21)	0.1014194	0.035941737
		Cooperation (22)	0.09640289	0.03416395
		Rerouting (23)	0.1158378	0.041051434
		Restorative Capacity (24)	0.1501135	0.053198303
		Geographical Segregation (25)	0.05937212	0.021040719

(availability, reliability, price, and serviceability). Tables 21, 22, 23 and 24 in the Appendix show the final weights of criteria/sub-criteria for other measures. Now, we form the matrix of weights of the sub-criteria for each measure as Table 9. It is equivalent to $W_{\text{need}-\text{critera}}$ matrix.

Afterward, we calculate the final weight of the sub-criteria based on the steady-state transition matrix customers' preferences (W^{*}_{need}). These weights are obtained by multiplying the transpose of W^{*}_{need} and transpose of Table 9. The achieved results are given in Table 10. It is in fact $W_{\text{Fcriteria}}$. The final weights of indicators will use to compute the final ranking of the suppliers.

5.3 Ranking suppliers

In this section, the results of ranking the alternatives (suppliers) are presented. At first, the decision matrix should be formed. To create the decision matrix, we gather the opinions of three groups of experts based on the linguistic variables which are shown in Table 11.

The decision matrix ($W_{\text{supplier}-\text{criteria}}$) is given in Table 25 in the Appendix. In this table, three experts in the supply department of the case study gave their opinion about each supplier on all sub-criteria base on linguistic variables. These linguistic variables have been altered to fuzzy numbers and then the average of three answers are been calculated in Table 26 in the Appendix.

Then, triangular fuzzy numbers are changed to their defuzzy forms using relation (9) (It should be noted that the crisp decision matrix is presented in Table 27 in the Appendix). The last step is prioritizing of suppliers based on Relation (15):

$$W_{\text{Fsupplier}} = W_{\text{supplier}-\text{criteria}} * W^{T}_{\text{Fcriteria}} \tag{15}$$

Finally, the suppliers are ranked and the results are reported in Table 12.

Table 9 Weights of the sub-criteria for each measure

Measure					
Sub-criteria	Performance	Availability	Reliability	Price	Serviceability
1	0.106965927	0.081651004	0.038585976	0.144433369	0.069893483
2	0.064379102	0.089986526	0.061959356	0.082044013	0.071482047
3	0.063527742	0.090886324	0.08069604	0.065431951	0.071482047
4	0.052512834	0.051365667	0.057467268	0.065768148	0.09751518
5	0.028747669	0.046522915	0.038580573	0.035583537	0.046842469
6	0.046745268	0.046649744	0.022040091	0.051528709	0.012907661
7	0.077989399	0.06656581	0.034176397	0.079370794	0.040252896
8	0.021182866	0.017194713	0.019716055	0.018522214	0.018880042
9	0.029351348	0.015076035	0.01609424	0.031989248	0.026075901
10	0.021288494	0.016977691	0.0156112	0.021050875	0.017733133
11	0.01862644	0.015076035	0.013663773	0.014503145	0.016803377
12	0.020822782	0.015076035	0.014197315	0.019195747	0.010359485
13	0.009093083	0.014037412	0.019377032	0.010568479	0.020398484
14	0.020933262	0.006796535	0.009489414	0.017849066	0.020273179
15	0.01862644	0.019944368	0.018891757	0.021639678	0.025347757
16	0.026193732	0.020476199	0.032332592	0.018325585	0.0280591
17	0.01862644	0.033710092	0.018591548	0.017849066	0.03611937
18	0.053100244	0.038183843	0.069897893	0.052591686	0.054398765
19	0.074839347	0.077232672	0.062599265	0.061309065	0.081792395
20	0.041051434	0.036204156	0.052907577	0.027585988	0.046738633
21	0.035941737	0.02716402	0.111020921	0.026430356	0.039280954
22	0.03416395	0.048985139	0.059931358	0.036574994	0.046107954
23	0.041051434	0.04268316	0.051801937	0.030123914	0.040100855
24	0.053198303	0.018920652	0.049639364	0.019606458	0.037464496
25	0.021040719	0.062633292	0.03073095	0.030123914	0.023690358

Based on the results of the proposed method, serviceability is the most important customer needs, and cost is the most important sub-criteria. Thus, based on relevant computations that satisfy customers in every period, supplier number four is the best supplier for the company.

6 Discussions

6.1 Findings

As mentioned before, since qualitative criteria include quality requirements and needs of customers, it is important to concentrate on customer needs and desires because they may change during the time (Asadabadi 2017a). Therefore, QFD which is a tool for translating requirements and needs of customers, was used integrated with Markov chains. However, the most important of customer needs which initially is, may lose its importance over time. So, a pattern that shows dynamics of needs priority is necessary which can be attained through Markov chains. These chains are able to suggest a tracing and predicting the pattern of constantly changing processes. Based on this study results, in a normal situation that there is no limitation for go shopping out of home, price, availability, and performance were the most important need of customers in buying online. It is obvious that as coronavirus continues to spread across the world and especially in Iran, the consumer preference and either behavior is changing. Furthermore, this priority is altered to serviceability, reliability, and availability in pandemic situation which are the requirements that make customers sure about their online buying. In this situation, every one prefers to cover his/her need when there is after-sales services and enough

Table 10 Final weights of the indicators based on customers' preference

Sub-criteria	Final weight based on preference of the customers
Cost	0.080430746
Delivery	0.07380494
Quality	0.076106833
Service	0.066815061
Trust	0.040695742
Technology capability	0.032786373
Financial	0.055531677
Environmental competencies	0.018985854
Environmental management system	0.022482068
Green design capability	0.018023464
Energy efficiency	0.015651194
Pollution control	0.015032698
Green R&D and Innovation	0.015751225
Eco-design recycling	0.014460052
Work safety & labor health	0.021126314
The rights of people	0.025784776
Social management commitment	0.026520347
Risk reduction	0.053870252
Responsiveness	0.072597865
Surplus inventory	0.042445518
Backup supplier contracting	0.042445518
Cooperation	0.051066318
Rerouting	0.042273166
Restorative capacity	0.03609535
Geographical segregation	0.03468388

reliability about the safety of receiving their online orders which are available, instead of thinking to price. So, if the changes in customer need and quality requirements not considered, there is the probability of wrong selection of a supplier in this special period. But by applying Markov chains, the supplier selected as the best is more accurate which we used for calculating the long-term changes in customer requirements weights. This result clearly shows that the price and performance, which used to be more important in initial time, are less important in COVID-19 pandemic outbreak because health is more important than any other issue, and most people think that they will buy the goods they need from online marketplaces and be able

Table 11 Transformation of linguistic variables into triangular fuzzy numbers-based on (Chen et al. 2010)

Degree of importance	Equivalent triangular fuzzy number
Very Poor (VP)	(0, 0, 0.2)
Poor (P)	(0.05, 0.2, 0.35)
Medium Poor (MP)	(0.2, 0.35, 0.5)
Fair (F)	(0.35, 0.5, 0.65)
Medium Good (MG)	(0.5, 0.65, 0.8)
Good (G)	(0.65, 0.8, 0.95)
Very Good (VG)	(0.8, 1, 1)

Table 12 Rank of the suppliers

Suppliers	Weights	Rank
1	0.209506011	4
2	0.239899246	3
3	0.259847873	2
4	0.286214102	1

to have good service and reliability in their purchase. Furthermore, managers should consider these elements when selecting suppliers if they want a good image in the customer mind in all three dimensions. However, in the pandemic of coronavirus, customers, themselves prefer serviceability and reliability more, but the marketplace should consider their power in buying so focus on costs of different suppliers and also with selecting the best quality, do not hurt its reliability. As availability was the third important requirement, responsiveness and risk reduction have a direct and effective relationship with this requirement.

Also, there are some criteria when decision-makers try to select suppliers and some of them are general criteria that have seven sub-criteria in this study (cost, delivery, quality, service, trust, technology capability, and financial). However, a sustainability-focused supplier selection is so crucial because it leads to increased business performance and competitive advantages (Luthra et al. 2017) which in this study, 10 sub-criteria are defined include environmental competencies, environmental management system, green design capability, energy efficiency, pollution control, green R&D and innovation, eco-design recycling, work safety & labor health, the rights of people, and social management commitment. On the other hand, resilient-focused criteria are also considered for facing risks and disruptions. So, in this study, there was a special view that focuses on the sustainable and resilient side simultaneously. Based on results, the general dimension is the most important dimension with the highest weight, followed by the resilience dimension and finally the sustainability dimension which is the least important. Of course, the difference in the weight of the sustainability dimension and the overall dimension is less than the difference in the weight of the sustainability and resilience dimensions, and this points to the fact that during the corona pandemic, the resilience dimension and actually having flexibility in managing supply and demand changes is more important than the sustainability dimension and considering the environmental and social effects.

Based on Table 9, From the customers' point of view, in terms of performance requirement, the sub-criteria include cost, financial, responsiveness, delivery, and quality are the most important, which all of them are related to the general dimension except responsiveness which is one of resilience sub-criteria. In terms of availability requirement, quality, delivery, cost, responsiveness, and financial have the most weights in which only responsiveness is related to resilience and others are related to general dimension again. In reliability requirement, the five highest weights are related to backup supplier contracting, quality, risk reduction, environmental management system, and delivery respectively. In reliability, two of the most important sub-criteria are related to resilience dimension (i.e., backup supplier contracting and risk reduction) and one of them is related to sustainability dimension (i.e., environmental management system) and the rest are for general dimension. From the price requirement point of view, the most important sub-criteria are cost, delivery, financial, service, quality, and responsiveness which are as same as performance and availability despite minor changes in order. Finally, from the serviceability requirement point of view, service, responsiveness, delivery, quality, and cost have the most scores which are similar to performance, availability, and price. But in them, the financial criterion was one of the most important, but here, instead of that, the service criterion is the most important. Therefore, it can be concluded that the importance of the sub-criteria from the perspective of each of the customer's preferences is almost equal, and from all requirements, the customers emphasize the most on cost, delivery, quality, finance, and responsiveness. However, based on Table 10, the final weights of all sub-criteria based on all customers preferences are cost, quality, delivery, responsiveness, and service which are exactly corresponds to the order of importance in each of the requirements, and only the service criterion has been placed instead of the financial criterion. Finally, in Table 12, the prioritization of potential suppliers is based on the simultaneous consideration of the importance of criteria and the importance of customer requirements. This result could have been different by considering customer preferences alone or prioritizing criteria alone. But in this case, it can be said that this prioritization can be more valid.

6.2 Comparing with other studies

Among the recent studies focused on supplier selection problem, Tong et al. (2022) concluded that cost, credit, and irregularity were the most important criteria which the cost was as same as our findings but not credit and irregularity. Based on (Van Thanh and Lan 2022) results, the most important indicators include product quality, employee empowerment, and production cost. But in this study, since the viewpoint of customers is focused, the employee empowerment is not considered as the most important ones. It is obvious that customers should not concern about human resources in their requirements. Besides, (Chai et al. 2023) identified economic capability, risk management, job creation, and waste management and (GHOSH et al. 2023) identified cooperation with suppliers for green purchasing, green design in especially resources consumption, and environmental planning in their study which all are different from this study results since the reason mentioned for previous study.

The supplier selection problem aims to choose reliable suppliers and it includes a multi-criteria decision-making process that considers qualitative and quantitative criteria (Hamdan and Cheaitou 2017). Dealing with this problem, there are many different tools and techniques which are useful.

In the case of criteria exploitation, Tavana et al. (2017) used QFD for the supplier selection criteria definition, Pramanik et al. (2017) also considered the criteria for supplier selection based on customer preferences through QFD. In addition, Vahidi et al. (2018) and Cheraghalipour and Farsad (2018) defined the criteria for their supplier selection problem via an integrated framework of SWOT-QFD. However, Asadabadi (2017) used the QFD-Markov chain for extracting their problem criteria and also their long term probable changes over time. The current study has tried to focus on Markovian-based QFD for extracting customer's needs, requirement, and preferences as the SRSS problem criteria. In other words, this study benefits from the advantages of the two aforementioned methods, concurrently.

Besides, the MCDM technique most used for ranking the candidate suppliers were AHP and ANP in the fuzzy or non-fuzzy environment. For instance, Büyüközkan and Çifçi (2011) and Tavana et al. (2017) used FANP, Azadnia et al. (2015) and Pramanik et al. (2017) used the fuzzy

AHP. Some authors also deployed fuzzy TOPSIS method for the ranking part of their problem. in this case, Fallahpour et al. (2017), Haldar et al. (2014), Sureeyatanapas et al. (2020), and Mohammed et al. (2018) used Fuzzy TOPSIS for the supplier prioritization. Tirkolaee et al. (2020), used the integrated framework of fuzzy ANP-DEMATEL-TOPSIS. Others focused on the Fuzzy Interference system such as Jain and Singh (2020), Amindoust (2018). VIKOR method was usually used by some researchers like Parkouhi and Ghadikolaei (2017). Among all of them discussed before, Gan et al. (2019) solved their selection problem based on Fuzzy BWM and GMo-RTOPSIS. They used fuzzy BWM for decision-makers weighting and GMo-RTOPSIS for supplier ranking. This study has used fuzzy best–worst-method as the tool for supplier ranking due to this method advantages mentioned before such as less need for data and more reliability.

6.3 Managerial implications

The implications of the current paper consist of three parts: (i) combining sustainable and resilient indicators in the SSP, (ii) incorporating the concept of customers' preferences in the sustainable-resilient supplier selection problem, and (iii) Development of an integrated Markov chain-QFD-FBWM model. This study has created a practical list of resilient-based sustainability attributes for suppliers' performance assessment. Specifically, 25 most important and applicable criteria were provided based on three aspects (general, sustainability, and resilient). Also, this paper has considered five customers' preferences namely performance, availability, reliability, price, and serviceability in the problem, which results in shifting the traditional SSP to the customer-based one. This study helps managers to better understand the way of incorporating customers' preferences, resiliency, and sustainability into the SSP. Also, the achieved outputs can help managers to identify the most important indicators of resilience and sustainability in the customer-based SSP. Moreover, an efficient decision-making framework was proposed to calculate the weights of the criteria and to assess the performance of the suppliers. By utilizing this framework, decision-makers can determine and choose suppliers that have appropriate performance in terms of financial, sustainability, and resiliency. Besides, the current study has provided a list of the indicators, which can very useful and applicable for decision-makers, especially in field of online marketplace. Decision-makers can understand the concept of sustainability and resiliency and can incorporate customers' preferences in their company.

6.4 Theoretical implications

This section is dedicated to presenting the theoretical implications of the current work. The main theoretical implications of this research can be described in two major parts: (i) incorporating customer preferences in the sustainable-resilient SSP, (ii) developing an efficient hybrid decision-making framework. Customer preferences are very important in supplier selection problem due to the importance of customer requirements. However, this concept has been rarely addressed in the literature. Indeed, there is no research that considered the customer preferences in the sustainable and resilient SSP. However, as aforementioned, each of the mentioned concepts (i.e., customer preferences, sustainability, and resiliency) is very important and practical. In this regard, the current paper has provided a list of indicators for sustainable-resilient SSP and also presented the list of customer requirements. On the other side, this study has applied the integrated Markov chain-QFD method to extract the customers' preferences and incorporate them into the research problem. Moreover, the current study proposed a decision-making framework (the integrated Markov-chain-QFD-FBWM), which has several advantages such as obtaining preferences of the customers employing Markov chain-QFD, enhancing the reliability of the outputs, and reducing computing burden utilizing the FBWM. It should be noted that this is the first application of this combination (Markov-chain-QFD-FBWM) in the supplier selection problem.

7 Conclusion and future studies

This research developed a Markovian-based fuzzy decision framework to investigate the customer-based sustainable-resilient supplier selection problem as one of the important issues in supply chain management. Due to the importance of the customer requirements, considering customer preferences can increase the efficiency of the supplier selection problem, drastically. Hence, this paper employed the combination of QFD and Markov transition matrix methods to incorporate customer preferences in the problem. Then, the hybrid approach based on the Markov transition matrix and FBWM is applied to calculate the weights of indicators and to rank the existed suppliers. Considering an online market in Iran as a case study, the proposed hybrid approach is executed and results showed that price, availability, and performance were the most important online marketplace customer preferences and then changed to serviceability, reliability, and availability in pandemic situation in Markov chain steady-state. In addition, the results showed that importance of the sub-criteria in all customer's preferences factors was almost same and based on them, cost, delivery, quality, finance, and responsiveness were the most important. However, based on the final weights of all sub-criteria cost, quality, delivery, responsiveness, and service were the most important at the end (i.e., considering all customers preferences). Finally, the potential suppliers of the case study were evaluated based on final weights which we were sure that customer point of view is combined in supplier evaluation.

Among the limitations of this study, we can mention the large number of criteria and sub-criteria in the survey questionnaires of experts and the lack of time for experts to answer. Also, in order to reach the target customers who can correctly receive opinions and logical requirements from them, it was another limitation of this study. On the other hand, there were a few numbers of previous researches in the field of evaluating customer preferences and considering the change of these preferences, which made the present research with limitations. Future research can combine the Markov transition matrix with artificial intelligence methods and proposed a hybrid Markovian-based artificial intelligence approach to investigate the SRSSP and comparing the results with the current study. Also, researchers can consider agile measures in the research problem and apply the proposed hybrid fuzzy framework to investigate the sustainable-resilient-agile supplier selection problem.

Appendix

A. Sub-criteria description

Sub-criteria	Description
Cost (1)	Product price, Transportation cost, Logistics cost, operational cost
Delivery (2)	Lead time, on-time orders, delivery robustness
Quality (3)	Quality of products, Defective rate, rejection order ratio
Service (4)	Product service, after-sales services, repair service
Trust (5)	Reputation, a good picture of the brand
Technology capability (6)	Technology level, Technology efficiency
Financial (7)	Financial capability, financial position
Environmental competencies (8)	Carbon emission measurement, toxic substances production
Environmental management system (9)	Efficiency of hazardous substance management system, environmental impact training
Green design capability (10)	Environmental importance, green image, green transportation
Energy efficiency (11)	Resource consumption rate, resource wasting rate, solid waste production
Pollution control (12)	Pollution production, use of clean technologies, environmental and ecological impacts control
Green R&D and innovation (13)	Green R&D and Innovation budget and efficiency
Eco-design recycling (14)	Waste recycling ratio, air emission reuse rate
Work safety & labor health (15)	Health and safety practices and training, safety of job, annual accidents and injury numbers
The rights of people (16)	Rights of employees and stakeholders, human community rights
Social management commitment (17)	Community development practices, supportive activities
Risk reduction (18)	Risk factors identifying, risk management, risk response
Responsiveness (19)	Velocity, Adaptive plans
Surplus inventory (20)	Additional available inventory for crises or emergency
Backup supplier contracting (21)	Availability of other suppliers
Cooperation (22)	collaboration
Rerouting (23)	Adaptive routing capability
Restorative capacity (24)	Budget assigned for restoration, restoration available resource
Geographical segregation (25)	Region segmentation

B. Factor load of model criteria

Criteria	Sub-criteria	Factor load	Cronbach's alpha coefficients $\alpha \geq 0.7$
Resilient	R01	0.780	0.936
	R02	0.830	
	R03	0.891	
	R04	0.917	
	R05	0.905	
	R06	0.863	
	R07	0.809	
	R08	0.641	
Sustainable	S01	0.896	0.948
	S02	0.935	
	S03	0.836	
	S04	0.571	
	S05	0.783	
	S06	0.774	
	S07	0.760	
	S08	0.840	
	S09	0.902	
	S10	0.936	
General	G01	0.850	0.907
	G02	0.619	
	G03	0.810	
	G04	0.775	
	G05	0.755	
	G06	0.885	
	G07	0.903	

C. Pairwise comparison matrices

See Tables 13, 14, 15, 16, 17, 18, 19 and 20.

Table 13 The average of pairwise comparison the best criteria with others based on three groups of the expert opinion

		Resilient	Sustainable	General
Based on performance	General (the best criterion)	(0.94,1.33,1.83)	(1.5,2,2.5)	(1,1,1)
Based on availability	General (the best criterion)	(0.94,1.33,1.83)	(2.5,3,3.5)	(1,1,1)
Based on reliability	Resilient (the best criterion)	(1,1,1)	(2.5,3,3.5)	(1.83,2.33,2.83)
Based on price	General (the best criterion)	(1.5,2,2.5)	(2.5,3,3.5)	(1,1,1)
Based on serviceability	General (the best criterion)	(0.94,1.33,1.83)	(1.5,2,2.5)	(1,1,1)

Table 14 The average of pairwise comparison the worst criteria with others based on three groups of the expert opinion

	Based on performance	Based on availability	Based on reliability	Based on price	Based on serviceability
	Sustainable (the worst criterion)	Sustainable (the worst criterion)	Sustainable (the worst criterion)	Sustainable (the worst criterion)	Sustainable (the worst criterion)
Resilient	(1.22,1.67,2.17)	(1.83,2.33,2.83)	(2.5,3,3.5)	(1.5,2,2.5)	(1.22,1.67,2.17)
Sustainable	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)	(1,1,1)
General	(1.5,2,2.5)	(2.5,3,3.5)	(2.17,2.67,3.17)	(2.5,3,3.5)	(1.5,2,2.5)

Table 15 The average of pairwise comparison the best sub-criteria of general with others based on three groups of the expert opinion

		Cost	Delivery	Quality	Service	Trust	Technology capability	Financial
Based on performance	Cost (the best criterion)	(1,1,1)	(1.83,2.33,2.83)	(1.83,2.33,2.83)	(2.5,3,3.5)	(3.5,4,4.5)	(2.83,3.33,3.83)	(1.83,2.33,2.83)
Based on availability	Delivery (the best criterion)	(2.17,2.67,3.17)	(1,1,1)	(2.5,3,3.5)	(1.22,1.67,2.17)	(2.5,3,3.5)	(3.5,4,4.5)	(2.5,3,3.5)
Based on reliability	Quality (the best criterion)	(2.17,2.67,3.17)	(1.22,1.67,2.17)	(1,1,1)	(1.5,2,2.5)	(2.17,2.67,3.17)	(3.5,4,4.5)	(2.5,3,3.5)
Based on price	Cost (the best criterion)	(1,1,1)	(2.5,3,3.5)	(2.5,3,3.5)	(2.5,3,3.5)	(3.5,4,4.5)	(3.17,3.67,4.17)	(2.17,2.67,3.17)
Based on serviceability	Service (the best criterion)	(2.17,2.67,3.17)	(1.5,2,2.5)	(2.17,2.67,3.17)	(1,1,1)	(2.83,3.33,3.83)	(3.5,4,4.5)	(2.17,2.67,3.17)

Table 16 The average of pairwise comparison the worst sub-criteria of general with others based on three groups of the expert opinion

	Based on performance Trust (the worst criterion)	Based on availability Technology capability (the worst criterion)	Based on reliability Technology capability (the worst criterion)	Based on price Trust (the worst criterion)	Based on serviceability Technology capability (the worst criterion)
Cost	(3.5,4,4.5)	(2.5,3,3.5)	(2.17,2.67,3.17)	(3.5,4,4.5)	(2.17,2.67,3.17)
Delivery	(2.83,3.33,3.83)	(3.5,4,4.5)	(3.17,3.67,4.17)	(2.5,3,3.5)	(3.17,3.67,4.17)
Quality	(2.83,3.33,3.83)	(2.17,2.67,3.17)	(3.5,4,4.5)	(2.5,3,3.5)	(3.17,3.67,4.17)
Service	(2.5,3,3.5)	(2.5,3,3.5)	(2.83,3.33,3.83)	(2.5,3,3.5)	(3.5,4,4.5)
Trust	(1,1,1)	(2.17,2.67,3.17)	(2.17,2.67,3.17)	(1,1,1)	(1.5,2,2.5)
Technology capability	(1.83,2.33,2.83)	(1,1,1)	(1,1,1)	(1.83,2.33,2.83)	(1,1,1)
Financial	(2.83,3.33,3.83)	(2.17,2.67,3.17)	(1.5,2,2.5)	(2.5,3,3.5)	(2.5,3,3.5)

Table 17 The average of pairwise comparison the best sub-criteria of resilience with others based on three groups of the expert opinion

Measure	The best criterion	Risk reduction	Responsiveness	Surplus inventory	Backup supplier contracting	Cooperation	Rerouting	Restorative capacity	Geographical segregation
Based on performance	Responsiveness	(1.83,2.33,2.83)	(1,1,1)	(2.17,2.67,3.17)	(2.5,3,3.5)	(2.5,3,3.5)	(2.17,2.67,3.17)	(1.83,2.33,3.5)	(3.5,4,4.6)
Based on availability	Responsiveness	(2.5,3,3.5)	(1,1,1)	(2.5,3,3.5)	(2.83,3.33,3.83)	(1.5,2,2.5)	(1.22,1.67,2.17)	(3.5,4,4.5)	(0.94,1.33,1.83)
Based on reliability	Backup supplier contracting	(1.22,1.67,2.17)	(1.5,2,2.5)	(2.5,3,3.5)	(1,1,1)	(2.17,2.67,3.17)	(1.83,2.33,2.83)	(1.5,2,2.5)	(3.5,4,4.5)
Based on price	Responsiveness	(0.94,1.33,1.83)	(1,1,1)	(1.83,2.33,2.83)	(1.5,2,2.5)	(1.22,1.67,2.17)	(1.83,2.33,2.83)	(2.5,3,3.5)	(1.83,2.33,2.83)
Based on serviceability	Responsiveness	(1.83,2.33,2.83)	(1,1,1)	(2.17,2.67,3.17)	(2.5,3,3.5)	(1.5,2,2.5)	(2.17,2.67,3.17)	(2.17,2.67,3.17)	(3.5,4,4.6)

Table 18 The average of pairwise comparison the worst sub-criteria of resilience with others based on three groups of the expert opinion

	Based on performance Geographical segregation (the worst criterion)	Based on availability Restorative capacity (the worst criterion)	Based on reliability Geographical segregation (the worst criterion)	Based on price Restorative capacity (the worst criterion)	Based on serviceability Geographical segregation (the worst criterion)
Risk reduction	(2.83,3.33,3.83)	(2.17,2.67,3.17)	(2.83,3.33,3.83)	(2.17,2.67,3.17)	(2.83,3.33,3.83)
Responsiveness	(3.5,4,4.5)	(3.5,4,4.5)	(2.5,3,3.5)	(2.5,3,3.5)	(3.5,4,4.5)
Surplus inventory	(2.5,3,3.5)	(1.83,2.33,2.83)	(2.17,2.67,3.17)	(1.5,2,2.5)	(2.5,3,3.5)
Backup supplier contracting	(2.17,2.67,3.17)	(1.5,2,2.5)	(3.5,4,4.5)	(1.5,2,2.5)	(2.17,2.67,3.17)
Cooperation	(2.17,2.67,3.17)	(2.5,3,3.5)	(2.5,3,3.5)	(2.17,2.67,3.17)	(2.17,2.67,3.17)
Rerouting	(2.5,3,3.5)	(2.5,3,3.5)	(2.17,2.67,3.17)	(1.83,2.33,2.83)	(2.17,2.67,3.17)
Restorative capacity	(2.83,3.33,3.83)	(1,1,1)	(2.17,2.67,3.17)	(1,1,1)	(1.83,2.33,2.83)
Geographical segregation	(1,1,1)	(3.17,3.67,4.17)	(1,1,1)	(1.83,2.33,2.83)	(1,1,1)

Table 19 The average of pairwise comparison the best sub-criteria of sustainable with others based on three groups of the expert opinion

Measure	The best criterion	Environmental competencies	Environmental management system	Green design capability	Energy efficiency	Pollution control	Green R&D and innovation	Eco-design recycling	Work Safety & labor health	The Rights of people	Social Management Commitment
Based on performance	Environmental management system	(1.83,2.33,2.83)	(1,1,1)	(1.83,2.33,2.83)	(1.22,1.67,2.17)	(1.22,1.67,2.17)	(2.5,3,3.5)	(1.83,2.33,2.83)	(1.22,1.67,2.17)	(1.22,1.67,2.17)	(1.22,1.67,2.17)
Based on availability	Social management commitment	(2.5,3,3.5)	(1.83,2.33,2.83)	(2.5,3,3.5)	(1.83,2.33,2.83)	(1.83,2.33,2.83)	(1.5,2,2.5)	(3.5,4,4.5)	(2.17,2.67,3.17)	(1.5,2,2.5)	(1,1,1)
Based on reliability	The Rights of people	(1.83,2.33,2.83)	(1.22,1.67,2.17)	(1.22,1.67,2.17)	(2.5,3,3.5)	(2.5,3,3.5)	(1.5,2,2.5)	(3.5,4,4.5)	(1.83,2.33,2.83)	(1,1,1)	(1.83,2.33,2.83)
Based on price	Environmental Management System	(0.94,1.33,1.83)	(1,1,1)	(1.83,2.33,2.83)	(1.5,2,2.5)	(1.5,2,2.5)	(2.5,3,3.5)	(1.83,2.33,2.83)	(1.83,2.33,2.83)	(1.5,2,2.5)	(1.5,2,2.5)
Based on serviceability	Social management commitment	(2.17,2.67,3.17)	(1.83,2.33,2.83)	(1.5,2,2.5)	(2.17,2.67,3.17)	(3.5,4,4.5)	(0.94,1.33,1.83)	(0.94,1.33,1.83)	(1.5,2,2.5)	(1.22,1.67,2.17)	(1,1,1)

Table 20 The average of pairwise comparison the worst sub-criteria of sustainable with others based on three groups of the expert opinion

	Based on performance Green R&D and Innovation (the worst criterion)	Based on availability Eco-design recycling (the worst criterion)	Based on reliability Eco-design recycling (the worst criterion)	Based on price Restorative capacity (the worst criterion)	Based on serviceability Pollution control (the worst criterion)
Environmental competencies	(2.17,2.67,3.17)	(2.17,2.67,3.17)	(1.5,2,2.5)	(2.17,2.67,3.17)	(2.17,2.67,3.17)
Environmental management system	(2.5,3,3.5)	(1.83,2.33,2.83)	(1.83,2.33,2.83)	(2.5,3,3.5)	(2.5,3,3.5)
Green design capability	(2.5,3,3.5)	(1.83,2.33,2.83)	(1.83,2.33,2.83)	(1.83,2.33,2.83)	(2.17,2.67,3.17)
Energy efficiency	(2.83,3.33,3.83)	(1.83,2.33,2.83)	(1.5,2,2.5)	(1.83,2.33,2.83)	(2.17,2.67,3.17)
Pollution control	(2.83,3.33,3.83)	(1.5,2,2.5)	(1.5,2,2.5)	(1.5,2,2.5)	(1,1,1)
Green R&D and innovation	(1,1,1)	(2.5,3,3.5)	(2.17,2.67,3.17)	(1,1,1)	(2.5,3,3.5)
Eco-design recycling	(2.17,2.67,3.17)	(1,1,1)	(1,1,1)	(2.17,2.67,3.17)	(2.5,3,3.5)
Work Safety & labor health	2.83,3.33,3.83)	(2.17,2.67,3.17)	(1.83,2.33,2.83)	(2.17,2.67,3.17)	(2.5,3,3.5)
The rights of people	(2.83,3.33,3.83)	(2.17,2.67,3.17)	(3.5,4,4.5)	(2.17,2.67,3.17)	(2.5,3,3.5)
Social management commitment	(2.83,3.33,3.83)	(3.5,4,4.5)	(2.17,2.67,3.17)	(2.17,2.67,3.17)	(3.5,4,4.5)

D. The final weights of indicators for other measures

Availability

See Table 21.

Table 21 The final weights of the indicators based on availability measure

Criteria	Weight	Sub-criteria	Local weight	Final weight
General	0.4736280	Cost	0.1723948	0.081651004
		Delivery	0.1899941	0.089986526
		Quality	0.1918939	0.090886324
		Service	0.1084515	0.051365667
		Trust	0.0982267	0.046522915
		Technology capability	0.09849448	0.046649744
		Financial	0.1405445	0.06656581
Sustainable	0.1743651	Environmental competencies	0.09861327	0.017194713
		Environmental management system	0.08646246	0.015076035
		Green design capability	0.09736863	0.016977691
		Energy efficiency	0.08646246	0.015076035
		Pollution control	0.08646246	0.015076035
		Green R&D and innovation	0.08050586	0.014037412
		Eco-design recycling	0.03897876	0.006796535
		Work safety & labor health	0.1143828	0.019944368
		The rights of people	0.1174329	0.020476199
		Social management commitment	0.1933305	0.033710092
Resilient	0.3520069	Risk reduction	0.1084747	0.038183843
		Responsiveness	0.2194067	0.077232672
		Surplus inventory	0.1028507	0.036204156
		Backup supplier contracting	0.077169	0.02716402
		Cooperation	0.1391596	0.048985139
		Rerouting	0.1212566	0.04268316
		Restorative capacity	0.0537508	0.018920652
		Geographical segregation	0.177932	0.062633292

Reliability

See Table 22.

Table 22 The final weights of the indicators based on reliability measure

Criteria	Weight	Sub-criteria	Local weight	Final weight
General	0.3335057	Cost	0.1156981	0.038585976
		Delivery	0.185782	0.061959356
		Quality	0.241963	0.08069604
		Service	0.1723127	0.057467268
		Trust	0.1156819	0.038580573
		Technology capability	0.0660861	0.022040091
		Financial	0.1024762	0.034176397

Table 22 (continued)

Criteria	Weight	Sub-criteria	Local weight	Final weight
Sustainable	0.1779649	Environmental competencies	0.1107862	0.019716055
		Environmental management system	0.09043491	0.01609424
		Green design capability	0.08772067	0.0156112
		Energy efficiency	0.07677791	0.013663773
		Pollution control	0.07977593	0.014197315
		Green R&D and innovation	0.1088812	0.019377032
		Eco-design recycling	0.05332183	0.009489414
		Work safety & labor health	0.1061544	0.018891757
		The rights of people	0.1816796	0.032332592
		Social management commitment	0.1044675	0.018591548
Resilient	0.4885293	Risk reduction	0.1430782	0.069897893
		Responsiveness	0.1281382	0.062599265
		Surplus inventory	0.1082997	0.052907577
		Backup supplier contracting	0.2272554	0.111020921
		Cooperation	0.1226771	0.059931358
		Rerouting	0.1060365	0.051801937
		Restorative capacity	0.1016098	0.049639364
		Geographical segregation	0.06290503	0.03073095

Price

See Table 23.

Table 23 The final weights of the indicators based on price measure

Criteria	Weight	Sub-criteria	Local weight	Final weight
General	0.5241605	Cost	0.2755518	0.144433369
		Delivery	0.1565246	0.082044013
		Quality	0.1248319	0.065431951
		Service	0.1254733	0.065768148
		Trust	0.06788672	0.035583537
		Technology capability	0.09830712	0.051528709
		Financial	0.1514246	0.079370794
Sustainable	0.1914931	Environmental competencies	0.09672523	0.018522214
		Environmental management system	0.1670517	0.031989248
		Green design capability	0.1099302	0.021050875
		Energy efficiency	0.07573717	0.014503145
		Pollution control	0.1002425	0.019195747
		Green R&D and innovation	0.05518987	0.010568479
		Eco-design recycling	0.09320997	0.017849066
		Work safety & labor health	0.113005	0.021639678
		The rights of people	0.09569841	0.018325585
		Social management commitment	0.09320997	0.017849066

Table 23 (continued)

Criteria	Weight	Sub-criteria	Local weight	Final weight
Resilient	0.2843464	Risk reduction	0.1849564	0.052591686
		Responsiveness	0.215614	0.061309065
		Surplus inventory	0.09701543	0.027585988
		Backup supplier contracting	0.09295126	0.026430356
		Cooperation	0.1286283	0.036574994
		Rerouting	0.1059409	0.030123914
		Restorative capacity	0.06895272	0.019606458
		Geographical segregation	0.1059409	0.030123914

Serviceability

See Table 24

E. The crisp decision matrix

See Tables 25, 26 and 27

Table 24 The final weights of the indicators based on serviceability measure

Criteria	Weight	Sub-criteria	Local weight	Final weight
General	0.4103758	Cost	0.1703158	0.069893483
		Delivery	0.1741868	0.071482047
		Quality	0.1741868	0.071482047
		Service	0.2376241	0.09751518
		Trust	0.1141453	0.046842469
		Technology capability	0.03145327	0.012907661
		Financial	0.09808789	0.040252896
Sustainable	0.2200498	Environmental competencies	0.08579895	0.018880042
		Environmental management system	0.1185	0.026075901
		Green design capability	0.08058691	0.017733133
		Energy efficiency	0.0763617	0.016803377
		Pollution control	0.04707791	0.010359485
		Green R&D and innovation	0.0926994	0.020398484
		Eco-Design Recycling	0.09212996	0.020273179
		Work safety & labor health	0.115191	0.025347757
		The rights of people	0.1275125	0.0280591
		Social management commitment	0.1641418	0.03611937
Resilient	0.3695744	Risk reduction	0.147193	0.054398765
		Responsiveness	0.2213151	0.081792395
		Surplus inventory	0.1264661	0.046738633
		Backup supplier contracting	0.106287	0.039280954
		Cooperation	0.1247596	0.046107954
		Rerouting	0.1085055	0.040100855
		Restorative capacity	0.101372	0.037464496
		Geographical segregation	0.06410173	0.023690358

Table 25 Decision matrix based on the linguistic variables

	1	2	3	4	5	6	7	8	9	10	11	12	13
Supplier 1	(G,VG,G)	(VP,P,MP)	(G,VG,G)	(P,P,MP)	(MG,MG,MG)	(G,G,F)	(F,F,MG)	(P,P,VP)	(P,P,VP)	(MP,P,MP)	(P,MP,F)	(MP,P,MP)	(MP,P,MP)
Supplier 2	(G,VG,MG)	(F,P,MG)	(G,VG,MG)	(P,F,F)	(G,G,VG)	(VP,P,P)	(MG,G,MG)	(MP,F,F)	(MP,F,F)	(F,MP,F)	(MG.F,MP)	(F,MP,F)	(F,MP,F)
Supplier 3	(G,F,G)	(G,G,MG)	(G,F,G)	(F,MG,G)	(VG,VG,MG)	(F,F,G)	(F,MG,G)	(MP,F,MG)	(MP,F,MG)	(G,MP,F)	(G,F,VG)	(G,MP,F)	(G,MP,F)
Supplier 4	(F,MG,G)	(VG.VG.G)	(F,MG,G)	(VG,VG,MG)	(MP,F,MG)	(G,G,VG)	(VG,G,F)	(G,MG,F)	(MG,F,MP)	(P,MP,F)	(MG,F,MP)	(MG,F,MP)	(G,MP,F)

	14	15	16	17	18	19	20	21	22	23	24	25
Supplier 1	(VP,MP,P)	(G,G,MG)	(F,MG,MP)	(MP,MP,MP)	(G,G,G)	(F,G,F)	(G,G,G)	(F,VG,F)	(G,VG,G)	(VP,VP,MP)	(F,F,MG)	(P,P,P)
Supplier 2	(G,MP,G)	(G,MG,MG)	(F,G,G)	(F,P,F)	(MG,F,MP)	(VG,VG,G)	(VG,G,VG)	(G,VG,F)	(G,F,VG)	(F,MP,VP)	(G,MG,MG)	(VP,VP,P)
Supplier 3	(F,VP,G)	(VG,G,VG)	(VG,F,MP)	(MG,F,F)	(F,F,MG)	(F,MG,G)	(G,G,MG)	(F,F,F)	(MG,MG,MG)	(F,F,MG)	(G,G,F)	(VP,VP,MP)
Supplier 4	(G,F,MG)	(VG,F,MG)	(F,MG,G)	(G,MG,F)	(G,MG,F)	(MG,MG,G)	(G,G,F)	(G,G,VG)	(MG,MG,F)	(MG,F,G)	(VG,F,G)	(MP,P,P)

Table 26 The average of fuzzy decision matrix

	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
Cost (1)	0.70	0.87	0.97	0.65	0.82	0.92	0.55	0.70	0.85	0.50	0.65	0.80
Delivery (2)	0.08	0.18	0.35	0.30	0.45	0.60	0.60	0.75	0.90	0.70	0.87	0.97
Quality (3)	0.70	0.87	0.97	0.65	0.82	0.92	0.55	0.70	0.85	0.50	0.65	0.80
Service (4)	0.10	0.25	0.40	0.25	0.40	0.55	0.50	0.65	0.80	0.70	0.88	0.93
Trust (5)	0.50	0.65	0.80	0.70	0.87	0.97	0.70	0.88	0.93	0.40	0.55	0.70
Technology capability (6)	0.55	0.70	0.85	0.03	0.13	0.30	0.45	0.60	0.75	0.70	0.87	0.97
Financial (7)	0.40	0.55	0.70	0.55	0.70	0.85	0.50	0.65	0.80	0.60	0.77	0.87
Environmental competencies (8)	0.03	0.13	0.30	0.30	0.45	0.60	0.35	0.50	0.65	0.50	0.65	0.80
Environmental management system (9)	0.03	0.13	0.30	0.30	0.45	0.60	0.35	0.50	0.65	0.50	0.65	0.80
Green design capability (10)	0.15	0.30	0.45	0.30	0.45	0.60	0.40	0.55	0.70	0.35	0.50	0.65
Energy efficiency (11)	0.20	0.35	0.50	0.35	0.50	0.65	0.60	0.77	0.87	0.20	0.35	0.50
Pollution control (12)	0.15	0.30	0.45	0.30	0.45	0.60	0.40	0.55	0.70	0.35	0.50	0.65
Green R&D and innovation (13)	0.15	0.30	0.45	0.30	0.45	0.60	0.40	0.55	0.70	0.35	0.50	0.65
Eco-design recycling (14)	0.08	0.18	0.35	0.50	0.65	0.80	0.33	0.43	0.60	0.40	0.55	0.70

Table 26 continued

	Supplier 1			Supplier 2			Supplier 3			Supplier 4		
	l	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*	*l*	*m*	*u*
Work safety & labor health (15)	0.60	0.75	0.90	0.55	0.70	0.85	0.75	0.93	0.98	0.50	0.65	0.80
The rights of people (16)	0.35	0.50	0.65	0.55	0.70	0.85	0.45	0.62	0.72	0.55	0.72	0.82
Social management commitment (17)	0.20	0.35	0.50	0.25	0.40	0.55	0.40	0.55	0.70	0.50	0.65	0.80
Risk reduction (18)	0.65	0.80	0.95	0.35	0.50	0.65	0.40	0.55	0.70	0.50	0.65	0.80
Responsiveness (19)	0.45	0.60	0.75	0.75	0.93	0.98	0.50	0.65	0.80	0.50	0.65	0.80
Surplus inventory (20)	0.65	0.80	0.95	0.75	0.93	0.98	0.60	0.75	0.90	0.55	0.70	0.85
Backup supplier contracting (21)	0.50	0.67	0.77	0.60	0.77	0.87	0.35	0.50	0.65	0.55	0.70	0.85
Cooperation (22)	0.70	0.87	0.97	0.60	0.77	0.87	0.50	0.65	0.80	0.70	0.87	0.97
Rerouting (23)	0.07	0.12	0.30	0.18	0.28	0.45	0.40	0.55	0.70	0.50	0.65	0.80
Restorative capacity (24)	0.40	0.55	0.70	0.55	0.70	0.85	0.55	0.70	0.85	0.60	0.77	0.87
Geographical segregation (25)	0.05	0.20	0.35	0.02	0.07	0.25	0.07	0.12	0.30	0.10	0.25	0.40

Table 27 The crisp decision matrix

	Supplier 1	Supplier 2	Supplier 3	Supplier 4
Cost (1)	0.86	0.81	0.70	0.65
Delivery (2)	0.19	0.45	0.75	0.86
Quality (3)	0.86	0.81	0.70	0.65
Service (4)	0.25	0.40	0.65	0.86
Trust (5)	0.65	0.86	0.86	0.55
Technology capability (6)	0.70	0.14	0.60	0.86
Financial (7)	0.55	0.70	0.65	0.76
Environmental competencies (8)	0.14	0.45	0.50	0.65
Environmental management system (9)	0.14	0.45	0.50	0.65
Green design capability (10)	0.30	0.45	0.55	0.50
Energy efficiency (11)	0.35	0.50	0.76	0.35
Pollution control (12)	0.30	0.45	0.55	0.50
Green R&D and innovation (13)	0.30	0.45	0.55	0.50
Eco-design recycling (14)	0.19	0.65	0.44	0.55
Work safety & labor health (15)	0.75	0.70	0.91	0.65
The rights of people (16)	0.50	0.70	0.61	0.71
Social management commitment (17)	0.35	0.40	0.55	0.65
Risk reduction (18)	0.80	0.50	0.55	0.65
Responsiveness (19)	0.60	0.91	0.65	0.65
Surplus inventory (20)	0.80	0.91	0.75	0.70
Backup supplier contracting (21)	0.66	0.76	0.50	0.70
Cooperation (22)	0.86	0.76	0.65	0.86
Rerouting (23)	0.14	0.29	0.55	0.65
Restorative capacity (24)	0.55	0.70	0.70	0.76
Geographical segregation (25)	0.20	0.09	0.14	0.25

F. The parameters definition in relations

Parameters	Definition	Related relation
Wn_i	ith customer preference or need	(1)/(6)
p_{ij}	The probability of moving from i^{th} state to j^{th} that is changing from Wn_i to Wn_j	(2)

Parameters	Definition	Related relation
y_{ijk}	The probability of customer changing preference from n_i to n_j at next period of time	(3)/(4)
b_{ijk}	The customers are willing to transfer from n_i to n_j at next period of time	(3)
c_{ik}	The number of customers who prefer n_i types of requirements at k^{th} period	(3)
p_{ij}^k	The probability of moving from i^{th} state to j^{th} that is changing from Wn_i to Wn_j after k period	(5)
W_{ij}	The weight of ith need based on jth criterion	(7)
u_{ij}	The normalized weight of ith supplier based on jth criterion	(12)/(13)
r_{ij}	The weight of ith supplier based on jth criterion	(13)

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Conflict of interest The authors declare that they have no conflict of interest.

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