Selecting a Green, Agile and Industry 4.0 Supplier With the Fuzzy-Swara-Bwm Integrated Method

Mehmet Ali Tas (✉ mehmetali.tas@tau.edu.tr)

Turk-Alman Universitesi <https://orcid.org/0000-0003-3333-7972>

Serap Akcan

Toros Universitesi

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SELECTING A GREEN, AGILE AND INDUSTRY 4.0 SUPPLIER WITH THE FUZZY-SWARA-BWM INTEGRATED METHOD

Mehmet Ali Taş¹, Serap Akcan²

(¹Turkish-German University, Department of Industrial Engineering, Engineering Faculty, İstanbul, Turkey)

(¹ mail: mehmetali.tas@tau.edu.tr) (¹ Corresponding Author)

(²Tarsus University, Department of Industrial Engineering, Engineering Faculty, Mersin, Turkey)

(² mail: serapakcan@tarsus.edu.tr)

Abstract

Businesses establish supply chains in order to continue their activities. Choosing the suppliers to take part in these supply chains poses many challenges in rapidly changing conditions. Environmental concerns in the public, competitive market structures, and developing technological opportunities affect the decision-making processes. Different criteria are taken into consideration instead of traditional criteria such as cost and service. In this study, green, agile, and Industry 4.0 dimensions and the criteria under these dimensions are defined. According to these, the problem of selecting the supplier that responds to the expectations of the markets and enables them to increase their competitiveness was discussed. Fuzzy SWARA and fuzzy BWM methods were applied in an integrated way to solve the supplier selection problem under these three dimensions. A real case study was also presented. In the study, the results obtained by creating different scenarios were compared and sensitivity analysis was made. The results obtained show that the hybrid method developed in this study is effective in supplier selection problems. As a result of the study, the most important evaluation dimension is "agile" and the most important criterion is "delivery speed".

Keywords: MCDM, Fuzzy SWARA, Fuzzy BWM, Fuzzy Logic, Supplier Selection.

1. Introduction

Although its structure is divided into various units, a business should actually be thought of as a single and interconnected organization. Organizations being able to manage all of their processes holistically will ensure that the obtained outputs are more successful. The supply chains that the businesses establish to continue operating have great importance at this point.

Supply chains express the planning, design and control of the service, product and information flow from the manufacturer to the customer and refers to the organizations including the supplier (Srivastava 2007). Since the selection of the suppliers in the supply chains will directly affect supply chain performance; it is necessary to determine the appropriate supplier. Businesses look at various criteria when selecting suppliers. These changing every day causes the supplier selection application to always have a new and current problem. Today, the purchased product/service is expected to be environmentalist in all utilization phases. The legal regulations being subjected to, pressure from factors such as manufacturers and consumers in the market, social responsibility and gaining advantage by reducing cost, have caused organizations to focus on environmental issues more seriously (Shaw et al. 2010).

Although manufacturing technologies make mass production quite easier, customers demand products that are adapted to their personal requests and want the product/service they purchased to be unique and customized. Predicting the expectations of customers beforehand provides great outcomes in the industry the business operates in. Intuitive industry analysis predictions based on experience can cause mistakes. Businesses that can observe the requests and expectations of customers with advanced methods can have competitive advantage.

The developing technology has affected people's entire lives, especially daily life. The Industry 4.0 philosophy has surfaced with the integration of technological facilities into industry. With this transformation that affected all processes, organizations are reconstructing their activities with Industry 4.0. Industry 4.0 presents great convenience for the control, management and intervention of all fields. It is clear that the Industry 4.0 philosophy and the usage of the technology it brings will be on the agenda of organizations even more.

In this study, three evaluation dimensions, "green", "agile" and "Industry 4.0" were created. A plastic product manufacturer was chosen because it operates in a sector that could be suitable for using these dimensions in supplier selection. This manufacturer will choose between four alternative suppliers. A detailed literature review has been done for the criteria in the three evaluation dimensions of supplier selection. Additionally, the opinions of the three decision makers (DM) working in the business subject to the application were consulted. A total of 21 evaluation criteria were selected as a result of the literature review and the combination of the DM opinions. Fuzzy SWARA (Step-Wise Weight Assessment Ratio Analysis), a multi-criteria decision making (MCDM) method, was chosen to determine the weights of the dimensions and criteria.

The fuzzy BWM (Best-Worst Method) was performed to evaluate alternatives. This method includes determining the best and worst alternatives and doing comparisons according to these two alternatives. This way, the DM can express the evaluation range created more accurately and be compared more consistently. After the four alternative suppliers have been evaluated alternatively, the criteria weights were changed, 21 different scenarios were created and the sensitivity of the results were checked.

Reviewing the literature, a study containing the recent fuzzy SWARA and BWM methods in an integrated way has not been encountered. These two methods used integrally, have been applied to a real life problem. Also, as seen as the result of the detailed literature review; the lack of a supplier problem using green, agile and Industry 4.0 dimensions together is another reason that makes the study unique.

This study consists of five titles. After the introduction part, studies about the topic in the literature are shown in the second title. In the third title, there is the methodology part involving the evaluation dimensions used in the application, MCDM and fuzzy logic. The fourth title consists of the application topic, determining the criteria and alternatives, and the application. In the final title, there is the study results and conclusions as a result of the application.

2. Literature review

Supplier selection problems using multi-criteria decision making methods related to green, agile and Industry 4.0, which constitute the scope of the research, have been investigated.

2.1. Green supplier selection

The concept of green supply chains can be summarized as an environmental reflection of the classical supply chain definition in its most general form. The topic of environment occupies an important place among the issues discussed by society and organizations (Kannan et al. 2015). Regardless of the sector, all businesses have duties and responsibilities to restore the ecological balance. When creating supply chains, it is necessary to organize the processes and activities that the business creates and the process and activities it is in, according to the determined green goals. In each moment of the implementation of the decisions taken in this direction, the environment should be given importance, green should be taken into consideration (Akcan and Taş 2019). In this way, the created supply chains should also be “green supply chains” (Zhu et al. 2008). Green supply chain management is also defined as a management strategy that takes the environmental effects and efficiency of resource usage in supply chains into account and aims to minimize the negative effects on the environment (Green et al. 2012). The activities changes between supply chain management and green supply chain management are shown Table 1.

Table 1. Changes between the supply chain management and green supply chain management

Activity	Supply chain management	Green supply chain management	Changes
1	Manufacturing	Green manufacturing	When manufacturing, having the ability to do manufacturing without harming the environment instead of doing only quality, flexible and cheap manufacturing.
2	Purchasing	Green purchasing	Prioritizing purchasing environment-friendly products, materials and services with low resource consumption.
3	Packaging	Green packaging	Using recyclable materials when doing packaging.
4	Logistics	Reverse logistics	Creating a logistics structure including reusing, recycling, recovering value activities.
5	Distribution	Green distribution	Creating a distribution network that consumes low CO ₂ producing, environment-friendly energy during the distribution of a service or product produced.

Kuo et al. (2015), focused on a green supplier selection of an electronic company that complies to the standards. DANP, the combination of ANP (Analytic Network Process) and DEMATEL (Decision Making Trial and Evaluation Laboratory) was used in the study for the criteria weights, VIKOR (Vlase Criteriailjumska Optimizacija Kompromisno Resenje) was used to evaluate the alternative green suppliers. Hashemi et al. (2015) performed ANP to find the criteria weights and advanced GRA (Gray Relational Analysis) for alternative selection in the green supplier selection

of an Iranian automobile manufacturer. Sivaprakasam et al. (2015) used AHP (Analytic Hierarchy Process) to evaluate criteria and alternatives in the green supplier selection of a textile manufacturing business. Freeman and Chen (2015) weighted subjective criteria with AHP and objective criteria with Entropy in the green supplier selection of a Chinese electronic machine manufacturer and made alternative selection with TOPSIS (Technique for Order Preference by Similarity to an Ideal Solution). Keshavarz Ghorabae et al. (2016) used interval type-2 fuzzy numbers in a green supplier selection study, in which the criteria weights were made with Entropy and the alternative ordering was made with WASPAS (Weighted Aggregated Sum Product Assessment). Wang Chen et al. (2016) made a green supplier selection for an optical prism manufacturer in Taiwan. In the study using triangular fuzzy numbers, the weights of the criteria were found with fuzzy AHP, the alternative weights were found with fuzzy TOPSIS. Yazdani et al. (2017) made a green supplier selection for the purchasing and logistics unit of a dairy company in Iran. In the study where the criteria weights were determined by QFD (Quality Function Deployment) and DEMATEL, the alternative evaluation was done with the COPRAS (Complex Proportional Assessment) method. Guo et al. (2017) used FAD (Fuzzy Axiomatic Design) to evaluate green supplier alternatives for a clothing manufacturer in Hong Kong and for the best green supplier selection application. Mousakhani et al. (2017) found the criteria weights with extended interval type-2 fuzzy TOPSIS in the green supplier selection of an automobile battery manufacturer in Iran, and found the alternative ordering with the interval type-2 fuzzy Hamming distance measure. Quan et al. (2018) as a group decision, made the selection of the best timber green supplier for a real estate company in China. LINMAP (Linear Programming Technique for Multidimensional Analysis of Preference) was used for the criteria weights, MULTIMOORA (Multi-Objective Optimization on the Basis of Ratio Analysis plus Full Multiplicative Form) was used to evaluate green suppliers. Banaeian et al. (2018) compared the results using fuzzy TOPSIS, fuzzy VIKOR and fuzzy GRA using triangular fuzzy numbers in the green supplier selection application of the agricultural food manufacturer for cooking oil. Gupta et al. (2019) made a green supplier selection application for an automobile company in India. Fuzzy AHP was used for criteria weights, fuzzy TOPSIS, fuzzy WASPAS and fuzzy MABAC (Multi Attributive Border Approximation Area Comparison) were used for alternative ordering, and the results were compared. Jayant and Agarwal (2019) employed DEMATEL to determine the relationship between the criteria, AHP for criteria weights and TOPSIS for alternative ordering in a green supplier selection application of an electronics sector company in India. Lu et al. (2019) made a green supplier selection for a business in the straw biomass industry in China. The criteria, cloud model were evaluated with the fuzzy AHP, and the alternative green suppliers were evaluated with the model established with the probability degree.

2.2. Agile supplier selection

Before defining the agile supply chain, the concept “agile” must be defined. According to Christopher (2000), agility is to increase the ability to meet demands by showing flexibility and rapid adaptation to suddenly shifting demands in manufacturing. Mangan and Lalwani (2016) defined agility as “coping with demand fluctuations”. The concept has started to be discussed in large scales with the expansion of this flexibility ability shown in manufacturing to the entirety of organizations, and the flexibility of all work flows and organizational activities. In fact, since the concept of agility emerges from a flexible manufacturing system, its main starting point can be considered as flexibility. The emergence of agility is related to the flexibility ability (Abdelilah et al. 2018). It can be also defined as adapting by moving quickly, thus creating environments that

have the chance to be sustainable, continuously aim for development, evaluate opportunities (Ulrich and Yeung, 2019).

Integrated structures and uninterrupted processes can be obtained with the spread of agility to the entirety of the organization. The activities within the business of the supply chains businesses create such as manufacturing, customer relationships, sales etc. are expected to be agile (Prater et al. 2001). The concept of an agile supply chain emerged with the integration of agility with supply chains. By means of agile supply chains and agile activities, it is possible to provide products and services customized for the customers and differentiated from the standard (Bottani, 2010). Activities that increase customer satisfaction can be conducted by monitoring customer demands in order to adapt to the rapid changes in agile supply chains (Alimardani et al. 2013). In agile supply chains, the interaction between suppliers should be flexible and should be sensitive to every type of change (Gunasekaran 1999). The selection of the mentioned suppliers is made for the compatible cooperation to be established. Although the agile criteria by which the supplier will be evaluated according to the products, raw material and services to be procured may differ slightly, businesses should have specific strategies suitable for the purposes of agile supplier selection (Beikhhakhian et al. 2015; Luo et al. 2009).

When past studies are examined, Zhou et al. (2008) used AHP and FCE (Fuzzy Comprehensive Evaluation) for the supplier selection in the agile supply chain for a machine tool manufacturer in China. Büyüközkan and Arsenyan (2009) made the supplier selection to be in the agile supply chain of an apparel company in Turkey. The triangular fuzzy numbers and fuzzy TOPSIS method was used for finding criteria weights, and the FAD method was used for the ordering of the agile suppliers. In the study, the most important criteria according to the weight of the criteria determined by fuzzy TOPSIS were the flexibility that the supplier can show in the amount of delivery, the agility in the information systems and private business structuring. Luo et al. (2009) performed an application for the electrical appliance and equipment manufacturing industry in China. The agile suppliers to take place in the agile supply chain of the industry were examined. GA (Genetic Algorithm) and ANN (Artificial Neural Networks) were used in the study. Wu and Barnes (2009) conducted the supplier selection model for the agile supply chain with a four-phase conceptual model using ANP and multi-purpose integer linear programming. Wu et al. (2009) examined the criteria priorities with ANP, the selection model of suppliers that will be working together in the agile supply chain and other business partners using MIMOP. Dotoli et al. (2015) touched on the determination of supplier selection and order quantities and made a selection from eight alternative suppliers for a small and medium size business hydraulic power plant manufacturer in Italy. Abdollahi et al. (2015) used agile and plain criteria together on the basis of organization and product. DEMATEL, ANP and DEA (Data Envelopment Analysis) were used to calculate the relationship between criteria, to find the criteria weights and ordering alternative supplies according to plain and agile criteria, respectively. 22 evaluation criteria consisting of two dimensions named plain and agile were used in the assessment of alternative suppliers in the plain and agile evaluation portfolio and performance improvements. Lee et al. (2015) made the selection of suppliers that have the best and most high quality operations according to the Pareto efficiency. An agile supplier selection was made considering the whip effect and the size of the inventory costs. One of the four criteria groups consist of agile criteria. In the study that used a total of 25 criteria, seven of which were agile, and fuzzy TOPSIS and fuzzy AHP were used for criteria weights and alternative supplier selection, two ordering strategies were examined and the results were compared. Beikhhakhian et al. (2015) evaluated the criteria in the evaluation of

agile supplier with the ISM method. Criteria weights were found with fuzzy AHP, alternative ordering was conducted with the fuzzy TOPSIS using triangular fuzzy numbers. In the study evaluating seven alternative agile suppliers, the most important criteria were found as, delivery speed, cost minimization and price, in order. Galankashi et al. (2016) applied triangular fuzzy numbers and fuzzy AHP (FAHP) for agile supplier selection. 12 sub-criteria under the four main criteria were used in the evaluation of the four agile suppliers. Matawale et al. (2016) made the supplier selection of the suppliers to take place in the agile supply chain of a business in the Indian automobile industry. The four main criteria and 11 sub-criteria were examined and fuzzy multi-level MCDM, fuzzy MOORA (Multi-Objective Optimization by Ratio Analysis) and fuzzy TOPSIS were used to evaluate agile suppliers. Sahu et al. (2016) conducted study evaluating the suppliers/partners taking place in the agile supply chain within the scope of comparison. In the study that transformed subjective evaluation data with fuzzy-based calculation module, the most suitable supplier/partner was selected using triangular interval value fuzzy numbers and TOPSIS. Four alternatives were evaluated with the seven main criteria and the 27 criteria under these criteria. The authors argued that the methods were efficient according to the results. Shariari and Pilevari (2016) conducted an agile supplier selection application for a cosmetic manufacturer. DEA was used to determine the efficiency of the suppliers. Better suppliers were selected as the alternatives to be evaluated and the Delphi method was chosen as the nine criteria evaluation measures. They have applied fuzzy VIKOR with trapezoidal fuzzy number data type. El Mokadem (2017) determined the criteria used in supplier selections with PCA (Principal Component Factor) analysis and surveys. They classified criteria as agility, plain and common selection criteria. The agility evaluation measures in the study were found as; flexibility, technology, service, research and development and manufacturing capacity. Dursun (2017) used fuzzy integral in the agile supplier selection problem of a hospital and evaluated the four agile suppliers in light of the criteria. Kumar et al. (2019) examined the performance criteria used in agile supplier selection. The 14 evaluation criteria determined by fuzzy DEMATEL using triangular fuzzy numbers were suggested as criteria that could be used in agile supplier selection.

2.3. Industry 4.0 dimension

The concept of Industry 4.0 has been defined in various ways. Kamble et al. (2018) defined it as the paradigm of information communication and continuous interaction by different physical devices using embedded electronics and technologies such as sensors connecting to a network or the internet. Communication and information exchange is no longer just between humans or between humans and machines, it can also occur among machines (M2M) (Roblek et al. 2016). Lu (2017) defines it as “an integrated, adapted, optimized, service focused and interoperable manufacturing process related to algorithms, big data and high technologies”, Hermann et al. (2016) defines it as the transition paradigm towards manufacturing processes that have communication between machines and resources and no central control. The concept of Industry 4.0 is a strategic transformation move that paves the way for the creation of “smart” environments all over the world with developing technological advancements (Weyer et al. 2015). Many fields including the workforce, society, the ecology, economy, information security etc. have also been affected by the changes this transformation has done in the industry, leading to the emergence of concepts such as logistics 4.0, education 4.0, healthcare 4.0, society 4.0 and the revision of all structures (Bongomin et al. 2020).

Technologies that triggered Industry 4.0 and are associated with Industry 4.0 can be compiled as; Internet of things (IoT), simulation, big data and analytics, augmented reality, additive manufacturing, horizontal and vertical system integration, cloud, autonomous robots, cybersecurity (Rüßmann et al. 2015). Another fruit of the process that has led to the emergence of changing paradigms such as health 4.0 and education 4.0 is the concept of supply chain 4.0. Supply chains have been digitalized and current technologies were included into their processes. The concept, which can also be referred to as the digital supply chain, can be expressed as innovative supply chain management, which is achieved by packaging, labelling, distribution and all other supply chain elements by taking advantage of the power of information technologies. Supply chain processes using Industry 4.0 technologies not only increase well known evaluation measures such as delivery speed, quality of service etc, but also increases business performances in dimensions such as environmental, social and societal (Dossou and Nachidi 2017). Selection of suppliers suitable for the Industry 4.0 era ensures the development of an effective relationship; this situation increases supply chain performance (Sachdeva et al. 2019). It is very important that suppliers support the Industry 4.0 transformation not only in their own internal processes, but also in the integration with all businesses and organizations in the supply chain.

Studies on this subject in the literature have been examined. Büyüközkan and Göçer (2018) conducted the digital supplier selection application of a business operating in airport operations in Turkey with interval value intuitive fuzzy numbers using AHP and ARAS methods. Sachdeva et al. (2019) proposed an integrated method for supplier selection that could compete with the Industry 4.0 era for an automobile manufacturer in India. In a study using intuitive fuzzy clusters, intuitive fuzzy weighted approach operator was used for DM opinions, Entropy was applied for criteria weights, TOPSIS was applied for alternative supplier selection. One of the five criteria used to evaluate the four suppliers was the efficiency of Industry 4.0 technologies. Also, the results were compared using fuzzy clusters and intuitive fuzzy clusters, where the weights were determined with Entropy. Özkaya et al. (2019) evaluated the criteria for the transition of businesses in the manufacturing sector in Turkey to Industry 4.0. ANP was used for the 4 main criteria and 26 criteria in the study, the most important criteria were found as; coordination and cooperation problem, lack of infrastructure and internet-based networks and digital culture insufficiency, respectively. Torkayesh et al. (2020) made the digital supplier selection application of the online retail store in Iran using BWM and WASPAS methods. WASPAS was employed to rank alternative digital suppliers, while BWM to add weight to seven criteria. Özbek and Yıldız (2020) implemented the digital supplier selection application in the digital supply chains created as a result of the Industry 4.0 transformation. Three digital suppliers were evaluated with the five main criteria and 20 sub-criteria for a business in the apparel sector in Turkey. Interval type-2 fuzzy numbers were used in the TOPSIS method, and sensitivity analysis was performed in 11 scenarios by changing the criteria weights. Sharma and Joshi (2020) used SWARA and WASPAS methods in digital supplier selection for the manufacturing industry. Hasan et al. (2020), in their study on flexible supplier selection in logistics 4.0; used ambiguous data transformed into triangular fuzzy numbers and used the fuzzy TOPSIS method in alternative ordering. Also, multiple choice goal programming was used to determine the order quantity. The assessment criteria, separated as quantitative and qualitative, consist of three main criteria and 19 sub-criteria. In the evaluation of the five suppliers, criteria that highlight Industry 4.0 abilities such as cyber security risk management and digitalization take place alongside traditional criteria such as flexibility criteria and cost.

2.4. Studies on fuzzy SWARA, fuzzy BMW methods

Studies using Fuzzy SWARA are mostly found in recent years. Mavi et al. (2017) used the fuzzy SWARA method to weight the criteria in the selection of sustainable third-party reverse logistics provider for the plastic industry. Four main criteria, economic, environmental, social and risk and 23 criteria under these criteria were considered, and 9 alternative providers were ranked with fuzzy MOORA. Similarly, Zarbakhshnia et al. (2018) focused on the evaluation of sustainable third party reverse logistics provider alternatives for an example from the automobile industry in Iran. Fuzzy SWARA was used for the weights of the criteria, and fuzzy COPRAS was used to evaluate alternatives. Perçin (2019) conducted an outsourcing provider selection to carry out the purchasing, manufacturing, planning and information systems processes of a business in the chemistry industry in Turkey. In the study where the evaluation criteria were determined by fuzzy SWARA, the alternative selection was made with FAD. Ighravwe and Oke (2019) employed fuzzy SWARA to find the weights of maintenance activities and fuzzy CORPAS to rank the factors in a study where the selection factors of maintenance technicians in the cement manufacturing plant were evaluated. Ren et al. (2019) found the criteria weights with fuzzy SWARA and alternative ranking with WASPAS in a location selection for electric vehicles in China.

The studies that apply fuzzy BWM were examined. In their two applications, Guo and Zhao (2017) used fuzzy BWM to evaluate the criteria to be considered to choose between the shipping types of products and to be bought. Amoozad Mahdiraji et al. (2018) used fuzzy BWM and COPRAS in a study examining the sustainable architecture of Iran. Omrani et al. (2018) used Taguchi, fuzzy BWM and TOPSIS in determining the most suitable combination of alternatives for energy manufacturing in Iran. Tian et al. (2018) selected the FMEA, entropy, fuzzy BWM and fuzzy VIKOR methods together in a study evaluating malfunction modes of CNC machines. Ghouschi et al. (2019) conducted FMEA to examine malfunctions in the processes of an automobile spare parts manufacturer in Iran. Weights of FMEA components for defect types were determined with fuzzy BWM. Z-MOORA was used to prioritize errors with triangular fuzzy numbers and Z-numbers. Momen et al. (2019) used FMEA and fuzzy BWM to determine the criteria and priorities in a study evaluating the reasons for postponing surgeries in Iran. Ijadi Maghsoodi et al. (2019) used fuzzy BWM to find the aesthetic, technical, practical and cost main criteria and sub-criteria weights in the selection of speakers among four design prototypes, and FAD to select among alternative prototypes. Moslem et al. (2020) applied fuzzy BWM to evaluate the factors for three levels determined by a survey evaluating the factors according to the results of a driver behavior questionnaire for road safety in Romania. Karimi et al. (2020) included two applications comparing the results of full fuzzy BWM and fuzzy AHP results for the examination of the four criteria for employee recruitment and 8 main and 21 sub-criteria related to hospital care in Iran.

The studies involving SWARA and BWM methods together was also examined. Zavadskas et al. (2018) applied rough numbers with SWARA in the evaluation of the criteria to be considered in the selection of railway wagons. They compared their results with the same number type and the results they found with AHP and BWM. Zolfani and Chatterjee (2019) evaluated the criteria used in the assessment of home furnishing materials in terms of sustainable design with SWARA and BWM and compared the results of the two methods.

As a result of the comprehensive literature review; a study integrally using fuzzy SWARA for criteria weights, the fuzzy BWM method for alternative evaluation has not been encountered. In

addition, as understood from the literature review; a supplier selection study discussing green, agile and Industry 4.0 as an evaluation dimension has also not been encountered.

3. Methodology

3.1. Fuzzy SWARA

Fuzzy SWARA follows the steps of the classic SWARA method defined by Keršulienė et al. (2010). The data type used in the evaluations is triangular fuzzy numbers. Fuzzy logic was used to reflect the DM opinions more accurately. SWARA was preferred because of it being recent, and the ease of use and calculation it provides. SWARA has $n-1$ pairwise comparisons. The method has less pairwise comparisons compared to the AHP method (Stanujkic et al. 2015). The steps of the method using fuzzy number data type instead of real numbers (Mavi et al. 2017):

Step 1. Ordering the selections: The selections that will be evaluated are ranked from most important to least important. When ranking for the n amount of selections on the list, it should be made sure that the most important selection is “1.”, the least important is “ n .”.

Step 2. Finding the $\tilde{s}_j$ value: It is the step that the selections that are ordered according to importance are compared. Starting from the second criteria in the importance ranking, comparisons are made with the criteria one step higher. The relative importance of the j . criteria compared to the $(j-1)$. rank has been expressed to be “the comparative importance of average value” and is shown as s_j (Keršulienė et al. 2010).

Step 3. Determining the $\tilde{k}_j$ coefficient: It is the step in which the criteria in the first place is summed with $\tilde{1}$, and the other criteria are summed with the comparative importance of the determined $\tilde{s}_j$ average respectively in Eq. (1).

$$\begin{cases} \tilde{1} & j = 1 \\ \tilde{s}_j + \tilde{1} & j > 1 \end{cases} \quad (1)$$

Step 4. Calculating the $\tilde{q}_j$ importance vector value: The fuzzy weights of the evaluated criteria are found in this step in Eq. (2).

$$\begin{cases} \tilde{1} & j = 1 \\ \frac{\tilde{x}_{j-1}}{\tilde{k}_j} & j > 1 \end{cases} \quad (2)$$

Step 5. Determining the $\tilde{w}_j$ criteria weights: The criteria weights found in the last step of the fuzzy SWARA method are normalized and the ultimate fuzzy weights are found. The results are defuzzified and specific values are obtained in Eq. (3).

$$\tilde{w}_j = \frac{\tilde{q}_j}{\sum_{k=1}^n \tilde{q}_k} \quad (3)$$

The mentioned operations are first done for the dimensions and the fuzzy weights of the dimensions will be found. Afterwards, they will be calculated for the criteria under the dimensions with SWARA, the local fuzzy weights found will be multiplied with the fuzzy weights of the dimensions and a separate global fuzzy weight will be obtained for each DM. Lastly, the arithmetic average of the global fuzzy weights of each DM will be taken to obtain a single opinion. The median value method was chosen for the defuzzification process because it does not contain excessive calculations and offers ease of use (Eq. 4):

$$w = \frac{l+m+u}{3} \quad (4)$$

The defuzzified fuzzy expressions are normalized to reach the final global weights of the criteria.

3.2. Fuzzy BWM

BWM is a MCDM method suggested by Rezaei (2015). It is based on the basic logic of determining the best/most demanded and the worst/least demanded alternatives among the selections to be evaluated and comparing them with other criteria (Rezaei 2015). It is a method that can be preferred because it is more consistent and requires less comparisons, and the results can be reached by applying the calculation steps with less information (Rezaei 2016). The fact that it does not have to create a full pairwise comparison matrix is a factor that reduces the number of calculations (Salimi and Rezaei 2018). Since BWM is quite new, it has not been used in many studies. The vectors created with the evaluations made according to the best and the worst, make it possible to check coherency. While AHP has $n(n-1)/2$ comparisons, BWM requires $2n-3$ pairwise comparisons. The method (similar to SWARA) requiring fewer pairwise comparisons, provides results with fewer calculations (Rezaei 2015). The comparison structure of the BWM method can be seen in Figure 1.

Fig. 1. The comparison structure in the BWM method (Rezaei 2015)

The BWM application consists of five steps:

Step 1. Determining the decision criteria to be evaluated. In the alternative selection application, the alternatives are similarly listed.

Step 2. The DM determines the best (the most important, most demanded) and worst (the least important, least demanded) among the alternatives. If there are more than one alternative thought to be the best or worst, a random one is chosen.

Step 3. It is the proportional expression of the preference degree of the best alternative chosen by the DM compared to the other alternatives. Through the conducted evaluations, the BO vector (Best-to-Others vector) comparing the best with others is obtained and is shown with A_B :

$$A_B = (a_{B1}, a_{B2}, a_{B3}, a_{B4}, \dots, a_{Bn})$$

Here a_{B1} shows the preference degree of the best alternative compared to the 1. alternative. Overall, it is possible to say that the expression a_{Bn} conveys the preference ratio between the best alternative and the n. alternative. The vector has 1 element since the best alternative will include an element to which it will be compared to ($a_{BB} = 1$).

Step 4. It is the proportional expression of the preference degree of all of the alternatives selected by the DM, except for the worst alternative, to the worst. Through the evaluations, the OW vector (Others-to-Worst vector) comparing the worst to the others is obtained (A_W):

$$A_W = (a_{1W}, a_{2W}, a_{3W}, a_{4W}, \dots, a_{nW})$$

Step 5. A linear programming model is established to find the weights of the alternatives. The weights are shown as $(w_1^*, w_2^*, w_3^*, w_4^*, \dots, w_n^*)$. The optimal weights should be $w_B/w_j = a_{Bj}$ and $w_j/w_W = a_{jW}$ for $w_B = w_j$ and $w_j = w_W$. The biggest absolute differences must be minimized to ensure the conditions. When the weight totals are 1 and the restriction of not taking a negative value are added (Eq. 5-12):

$$\min \max_j \left\{ \left| \frac{w_B}{w_j} - a_{Bj} \right|, \left| \frac{w_j}{w_W} - a_{jW} \right| \right\} \quad (5)$$

Restrictions:

$$\sum_j w_j = 1 \quad (6)$$

$$w_j \geq 0, \forall_j \quad (7)$$

The problem is transformed into a linear programming model.

$$\min \xi \quad (8)$$

Restrictions:

$$\left| \frac{w_B}{w_j} - a_{Bj} \right| \leq \xi, \forall_j \quad (9)$$

$$\left| \frac{w_j}{w_W} - a_{jW} \right| \leq \xi, \forall_j \quad (10)$$

$$\sum_j w_j = 1 \quad (11)$$

$$w_j \geq 0, \forall_j \quad (12)$$

The optimal weights ($w_1^*, w_2^*, w_3^*, w_4^*, \dots, w_n^*$) and ξ (consistency measure of the comparisons) values are calculated with the problem solution created (van de Kaa et al. 2018; Yadollahi et al. 2018). ξ values are divided with the corresponding value in the consistency index (CI) shown in Table 2. In order to find the value in the consistency index table, the value in the BO vector of the alternative corresponding to one in the OW vector is looked at. Similarly, the value in the OW vector of the alternative corresponding to one in the BO vector gives the same result (a_{BW}). The consistency ratio values are expected to be close to zero. It is accepted that the closer the value is to zero, the more consistent it is (Rezaei 2015). The consistency ratio is shown in Equation 13.

$$CR = \frac{\xi^*}{CI} \quad (13)$$

Table 2. Consistency index Table (Guo and Zhao 2017)

a_{BW}	EIM	WIM	FIM	VIM	AIM
CI	3.00	3.80	5.29	6.69	8.04

The steps followed in the application are shown in Figure 2.

Fig. 2. The steps of the proposed methodology

4. Case Study

As the application subject, one of the largest plastic manufacturers in the Mediterranean region of Turkey was discussed. The business is one of the largest in the industry and has been manufacturing for large projects and individual consumers for over 50 years. It imports raw materials and semi-finished goods from various regions of the world, especially the People's

Republic of China, and uses them in the manufacturing processes. It brings the manufactured products to the end consumer through vendors in the country. Also, it exports products to numerous countries.

The increasing environmental concern of today has also closely affected the plastic industry in which it is involved and has pushed the business to take responsibility in this regard. The business having the ISO 14001 Environmental Management System also expects the suppliers in its supply chain to abide by the standards in terms of the environment, respect nature and support the environmental performance of the business. The purpose of the business taking personalized product requests from customers through vendors is to provide customizable products and services according to the requests and expectations of the corporate customers in the business website, mobile application. The suppliers to work with being flexible suppliers increases the ability to respond to the rapidly changing requests and expectations of the consumers of the business. The business having the ISO/IEC 27001 Information Security Management System standards certification, wishes to adapt to the wind of change that the Industry 4.0 created in the entire world and makes investments to develop their processes with new technologies. As the new supplier selection model of the business, determining a supplier selection that is suitable for green, agile and Industry 4.0 were applied with MCDM methods. The three DM who were consulted are included in Table 3.

Table 3. Identification of DMs

DM	Title	Education	Experience
DM ₁	Supply chain manager	Post graduate	11 years
DM ₂	Purchasing manager	Graduate	14 years
DM ₃	Project engineer	Graduate	8 years

Alternatives will be evaluated with the fuzzy BWM, considering the weighted criteria one by one. By multiplying the obtained alternative evaluation results with the criteria weights, the values that the alternatives have in relation to the criteria will be calculated. The ordering of the alternatives will be determined according to the average of the total value of each alternative.

The main criteria to be used in the supplier selection application were divided into three criteria dimensions as; green (B₁), agile (B₂) and Industry 4.0 (B₃). A wide literature review was conducted to select the evaluation measures to be included under the main criteria and DM opinions were also used (Table 4-6).

Table 4. Green supplier selection criteria

Green criteria (C _{1n})	Criteria	Definition	References
C ₁₁	Environmental management system	The best known is ISO 14001. It is the certification system developed for the purpose of proving the environmental management skills of organization; to observe and manage the environmental effects resulting from their activities (Badri Ahmadi et al. 2017).	(Kuo et al. 2015), (Badri Ahmadi et al. 2017)

C ₁₂	Green image	It expresses the ability to prioritize manufacturing green products in line with environmental standards and the perception of this on the consumer (Mousakhani et al. 2017).	(Wang Chen et al. 2016), (Mousakhani et al. 2017)
C ₁₃	Pollution control	It is the control and monitoring of the pollution caused by the activities of organizations in order not to harm nature (Lin et al. 2017).	(Lin et al. 2017), (Wan et al. 2017)
C ₁₄	Management commitment and support	It is having an environmentalist perspective and acting with social responsibility within the organization, with the support and encouragement of senior and mid-level managers.	(Jiang et al. 2018), (Haeri and Rezaei 2019)
C ₁₅	Reverse logistics	It is green activity, which expresses the increased value of products being transported backwards from their final destination (consumer) (Li et al. 2017).	(Uygun and Dede 2016), (Liang and Chong 2019)
C ₁₆	Waste management	It expresses the suppliers reducing, measuring waste and keeping it under surveillance throughout their activities (Topaloglu et al. 2018).	(Handfield et al. 2002), (Freeman and Chen 2015)
C ₁₇	Green packaging	It refers to the usage of environmentally friendly wrapping and packing materials that will not negatively affect nature by rapidly dissolving or degrading in nature (Kumar et al. 2017).	(Büyüközkan and Çifçi 2012), (Kumar et al. 2017)

Table 5. Agile supplier selection criteria

Agile criteria (C _{2n})	Criteria	Definition	References
C ₂₁	Delivery flexibility	It is the degree to which the supplier can respond to changes in the delivery requirements and adapt to changes in planned delivery times (Aramyan et al. 2007; Lee et al. 2015).	(Gunasekaran 1999), (Lee et al. 2015)
C ₂₂	Manufacturing flexibility	The ability to react to instant changes through the flexibility shown in the manufacturing processes, increases the agility of supply chains (Prater et al. 2001).	(Gerwin 1993), (Alimardani et al. 2013)
C ₂₃	Resource flexibility	It is the ability to benefit effectively so as to meet changing requirements in the supply of owned components (Matawale et al. 2016).	(Prater et al. 2001), (Matawale et al. 2016)
C ₂₄	Delivery speed	It is the degree to which the supplier meets the delivery speed expectations (Lee et al. 2015).	(Lee et al. 2015), (Beikhhakhian et al. 2015)
C ₂₅	Agile customer awareness	It is the criteria suggesting a supplier's degree of the ability to respond to customer demands (Lee et al. 2015).	(Lee et al. 2015)

C ₂₆	Information sharing	It refers to the dynamic information sharing that will increase the agility performance of a supplier by doing network integration (Christopher 2000).	(Christopher 2000), (Galankashi et al. 2016).
C ₂₇	Cooperation ability	It expresses the supplier's degree of partnership with supply chain entities in processes by providing process integration (Matawale et al. 2016).	(Matawale et al. 2016), (Sahu et al. 2016)

Table 6. Supplier selection criteria in line with Industry 4.0

Industry 4.0 criteria (C _{3n})	Criteria	Definition	References
C ₃₁	Industry 4.0 technology usage	It is the usage level of Industry 4.0 technologies such as sensors, augmented reality, simulation etc.	(Sachdeva et al. 2019), (Özbek and Yildiz 2020)
C ₃₂	Industry 4.0 personnel	It displays the Industry 4.0 usage skills and the level of training of the employees.	(Lichtblau et al. 2014), (Sharma and Joshi 2020)
C ₃₃	Digital customer relationships	It expresses the usage of customer data, thus the digitalization of products and services.	(Schumacher et al. 2016)
C ₃₄	Smart factory	It shows the obtained information and the possessed innovative technological infrastructures, the level of digitized manufacturing through information technologies.	(Lichtblau et al. 2014)
C ₃₅	Cyber security	It is the application of cyber security systems in order to protect the data created during the processes (Sharma and Joshi 2020).	(Ghobakhloo 2020), (Sharma and Joshi 2020)
C ₃₆	Industry 4.0 strategy	It is the effort to make the business have the Industry 4.0 strategy, and to create business models, operations and the organization culture in line with Industry 4.0.	(Schumacher et al. 2016), (Salam, 2019)
C ₃₇	Information systems usage	It refers to the big analysis, storage, integration and management of the emerged big data.	(Schuh et al. 2017), (Özbek and Yildiz 2020)

The four alternative suppliers operating domestically and overseas were names as; A₁, A₂, A₃ and A₄. The fuzzy number equivalents of the linguistic variables used by the three DMs to evaluate the dimensions and the criteria under them are given in Table 7 (Mavi et al. 2017; Sumrit 2020).

Table 7. The fuzzy number conversions of linguistic variables used in the criteria evaluation (Chang 1996)

Linguistic Variables	Linguistic Variable Codes	Fuzzy Numbers
Equally Important	EI	(1,1,1)
Moderately Less Important	MI	(2/3, 1, 3/2)
Less Important	LI	(2/5, 1/2, 2/3)
Very Less Important	VI	(2/7, 1/3, 2/5)
Much Less Important	ML	(2/9, 1/4, 2/7)

Firstly, the dimensions will be evaluated among themselves. It was asked that the DM ranked the dimensions from most important to least important. The dimension weights calculated with the DM evaluation and fuzzy SWARA are in Table 15 in Appendix.

Afterwards, the criteria under the dimensions were evaluated by the three DMs and their weights were determined with fuzzy SWARA. The green criteria evaluation of DM₁ is in Table 16 in Appendix as an example.

The dimension weights of DM₁, DM₂ and DM₃ determined with fuzzy SWARA are multiplied with the calculated criteria weights to find the fuzzy criteria weights. The arithmetic average of the calculated fuzzy numbers were taken to determine the final fuzzy weights (Table 8). The median method was used in the defuzzification calculation (Keshavarz Ghorabae et al. 2018; Perçin 2019). The fuzzy numbers are turned into specific numbers and normalized to reach their final weight values. The final criteria weight values found are included in Table 9.

Table 8. The final fuzzy weights of the dimensions and criteria

	Fuzzy Weights		Fuzzy Weights		Fuzzy Weights
D₁	(0.2232, 0.2644, 0.3158)	D₂	(0.3816, 0.4205, 0.4647)	D₃	(0.2697, 0.3150, 0.3680)
C ₁₁	(0.0208, 0.0363, 0.0620)	C ₂₁	(0.0716, 0.1025, 0.1446)	C ₃₁	(0.0815, 0.1099, 0.1490)
C ₁₂	(0.0199, 0.0377, 0.0667)	C ₂₂	(0.0329, 0.0503, 0.0764)	C ₃₂	(0.0272, 0.0461, 0.0744)
C ₁₃	(0.0407, 0.0516, 0.0708)	C ₂₃	(0.0514, 0.0685, 0.0958)	C ₃₃	(0.0116, 0.0232, 0.0431)
C ₁₄	(0.0198, 0.0323, 0.0527)	C ₂₄	(0.0966, 0.1273, 0.1700)	C ₃₄	(0.0252, 0.0422, 0.0688)
C ₁₅	(0.0418, 0.0571, 0.0786)	C ₂₅	(0.0102, 0.0201, 0.0371)	C ₃₅	(0.0261, 0.0438, 0.0715)
C ₁₆	(0.0234, 0.0321, 0.0467)	C ₂₆	(0.0087, 0.0200, 0.0406)	C ₃₆	(0.0147, 0.0293, 0.0534)
C ₁₇	(0.0083, 0.0171, 0.0342)	C ₂₇	(0.0176, 0.0314, 0.0541)	C ₃₇	(0.0117, 0.0202, 0.0350)

Table 9. The final weights of the dimensions and criteria

Dimension	Global Weight	Dimension	Global Weight	Dimension	Global Weight
D ₁	0.2658	D ₂	0.4191	D ₃	0.3151

C ₁₁	0.0374	C ₂₁	0.1000	C ₃₁	0.1068
C ₁₂	0.0390	C ₂₂	0.0501	C ₃₂	0.0464
C ₁₃	0.0512	C ₂₃	0.0677	C ₃₃	0.0245
C ₁₄	0.0329	C ₂₄	0.1236	C ₃₄	0.0428
C ₁₅	0.0557	C ₂₅	0.0212	C ₃₅	0.0444
C ₁₆	0.0321	C ₂₆	0.0218	C ₃₆	0.0306
C ₁₇	0.0187	C ₂₇	0.0324	C ₃₇	0.0210

The weights of the dimensions and criteria were found with fuzzy SWARA. The most important dimension was the agility dimension with the final weight of 0.4191. The dimension ranking second was the Industry 4.0 with 0.3151, the last one was the green dimension with 0.2658. It was seen that the most important criteria was delivery speed (C₂₄). The most important second criteria was the usage of Industry 4.0 technologies (C₃₁), the third was delivery flexibility (C₂₁), the fourth was resource flexibility (C₂₃) and the fifth was reverse logistics (C₁₅). The criteria weights and ranking is shown in Table 10.

Table 10. The ranking of criteria weights

D ₁	Weight	Rank	D ₂	Weight	Rank	D ₃	Weight	Rank
D ₁	0.2658	3	D ₂	0.4191	1	D ₃	0.3151	2
C ₁₁	0.0374	12	C ₂₁	0.1000	3	C ₃₁	0.1068	2
C ₁₂	0.0390	11	C ₂₂	0.0501	7	C ₃₂	0.0464	8
C ₁₃	0.0512	6	C ₂₃	0.0677	4	C ₃₃	0.0245	17
C ₁₄	0.0329	13	C ₂₄	0.1236	1	C ₃₄	0.0428	10
C ₁₅	0.0557	5	C ₂₅	0.0212	19	C ₃₅	0.0444	9
C ₁₆	0.0321	15	C ₂₆	0.0218	18	C ₃₆	0.0306	16
C ₁₇	0.0187	21	C ₂₇	0.0324	14	C ₃₇	0.0210	20

The three most important criteria among the criteria in the green dimension are reverse logistics (C₁₅), pollution control (C₁₃) and green image (C₁₂), respectively. The order of the criteria in the green dimension:

$$C_{15} > C_{13} > C_{12} > C_{11} > C_{14} > C_{16} > C_{17}.$$

The most important criteria in the agility dimension, delivery speed (C₂₄), was also found to be the criteria with the highest value among the 21 criteria. The order of the criteria in the agility dimension:

$$C_{24} > C_{21} > C_{23} > C_{22} > C_{27} > C_{26} > C_{25}.$$

The most important criteria in the Industry 4.0 dimension is the usage of Industry 4.0 technologies (C₃₁). The order of the criteria in this dimension:

$$C_{31} > C_{32} > C_{35} > C_{34} > C_{36} > C_{33} > C_{37}$$

Fuzzy BWM was used to examine alternatives in the second part of the study. The three DMs evaluated the four alternative suppliers with the help of linguistic variables. The fuzzy number conversions for the linguistic variables used are shown in Table 11. The three DMs determined the best and worst alternatives for each criterion (Table 17 in Appendix).

Table 11. The fuzzy number conversions of the linguistic variables used in the evaluation of alternatives (Guo and Zhao 2017; Omrani et al. 2018)

Linguistic Variables	Code	Fuzzy Number
Equally Importance	EIM	(1, 1, 1)
Weakly Important	WIM	(2/3, 1, 3/2)
Fairly Important	FIM	(3/2, 2, 5/2)
Very Important	VIM	(5/2, 3, 7/2)
Absolutely Important	AIM	(7/2, 4, 9/2)

Afterwards, the linguistic evaluations that will make up the BO and OW vectors were carried out by the three DMs for each criterion. The linguistic evaluations were taken from Table 11. The fuzzy number equivalents and defuzzified values of the evaluations were found with the median method. The evaluation of the alternatives in relation to green image (C_{12}) by DM₁ is seen in Table 18 and Table 19 in Appendix as an example. Considering the created evaluation Tables, a total of 63 BWM models were established for the three DMs. The solutions of the models established for DM₁, DM₂ and DM₃ and the alternative evaluation results found, ξ^* values and consistency ratios are included in Table 20 in Appendix, subsequently.

As the consistency ratios found were quite close to zero, the results can be accepted as consistent. Later in the application, the results were combined by multiplying the criteria weights found with the fuzzy SWARA method with the alternative evaluation results determined with the fuzzy BWM. The total scores of the alternatives are in the bottom total row (Table 12).

The final evaluation results of the alternatives are revealed by taking the arithmetic average of the total values found for each DM (Table 13).

Table 12. Combining the fuzzy SWARA and fuzzy BWM results

	DM ₁				DM ₂				DM ₃			
	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄	A ₁	A ₂	A ₃	A ₄
C ₁₁	0.0093	0.0164	0.0071	0.0046	0.0047	0.0137	0.0113	0.0077	0.0067	0.0179	0.0077	0.0051
C ₁₂	0.0100	0.0066	0.0183	0.0042	0.0048	0.0173	0.0101	0.0067	0.0078	0.0195	0.0078	0.0039
C ₁₃	0.0102	0.0102	0.0256	0.0051	0.0131	0.0087	0.0240	0.0054	0.0049	0.0219	0.0122	0.0122
C ₁₄	0.0050	0.0120	0.0084	0.0075	0.0078	0.0141	0.0078	0.0031	0.0041	0.0082	0.0157	0.0050
C ₁₅	0.0182	0.0208	0.0111	0.0056	0.0100	0.0151	0.0230	0.0075	0.0057	0.0212	0.0128	0.0159
C ₁₆	0.0122	0.0074	0.0033	0.0092	0.0096	0.0031	0.0137	0.0057	0.0080	0.0141	0.0061	0.0040
C ₁₇	0.0019	0.0037	0.0094	0.0037	0.0021	0.0054	0.0070	0.0042	0.0034	0.0051	0.0077	0.0025
C ₂₁	0.0229	0.0152	0.0255	0.0363	0.0376	0.0291	0.0222	0.0111	0.0203	0.0102	0.0385	0.0310
C ₂₂	0.0177	0.0125	0.0074	0.0125	0.0101	0.0079	0.0101	0.0220	0.0191	0.0158	0.0044	0.0108

C ₂₃	0.0246	0.0173	0.0103	0.0155	0.0240	0.0168	0.0101	0.0168	0.0251	0.0109	0.0071	0.0247
C ₂₄	0.0319	0.0136	0.0231	0.0550	0.0469	0.0153	0.0307	0.0307	0.0530	0.0118	0.0294	0.0294
C ₂₅	0.0062	0.0047	0.0024	0.0080	0.0106	0.0021	0.0042	0.0042	0.0066	0.0022	0.0082	0.0043
C ₂₆	0.0059	0.0040	0.0020	0.0099	0.0054	0.0054	0.0027	0.0083	0.0045	0.0108	0.0022	0.0043
C ₂₇	0.0110	0.0030	0.0080	0.0103	0.0139	0.0062	0.0046	0.0077	0.0080	0.0123	0.0080	0.0040
C ₃₁	0.0119	0.0237	0.0401	0.0311	0.0094	0.0408	0.0230	0.0336	0.0119	0.0237	0.0237	0.0475
C ₃₂	0.0039	0.0193	0.0155	0.0077	0.0044	0.0197	0.0139	0.0083	0.0085	0.0171	0.0145	0.0063
C ₃₃	0.0032	0.0053	0.0076	0.0083	0.0064	0.0040	0.0115	0.0026	0.0062	0.0115	0.0026	0.0042
C ₃₄	0.0078	0.0039	0.0194	0.0117	0.0097	0.0179	0.0097	0.0055	0.0048	0.0124	0.0161	0.0095
C ₃₅	0.0044	0.0166	0.0145	0.0089	0.0089	0.0089	0.0222	0.0044	0.0115	0.0198	0.0083	0.0049
C ₃₆	0.0048	0.0062	0.0062	0.0134	0.0031	0.0061	0.0061	0.0153	0.0076	0.0076	0.0116	0.0038
C ₃₇	0.0030	0.0040	0.0090	0.0050	0.0060	0.0048	0.0080	0.0022	0.0022	0.0080	0.0048	0.0060
Tot.	0.2260	0.2264	0.2742	0.2734	0.2485	0.2626	0.2759	0.2130	0.2297	0.2817	0.2494	0.2392

Table 13. The evaluation results of the alternatives

	DM ₁	DM ₂	DM ₃	Average
A ₁	0.2260	0.2485	0.2297	0.2347
A ₂	0.2264	0.2626	0.2817	0.2569
A ₃	0.2742	0.2759	0.2494	0.2665
A ₄	0.2734	0.2130	0.2392	0.2419

As a result of the applied methods, the best alternative supplier was found as A₃. The order of the suppliers were found as A₃ > A₂ > A₄ > A₁. In the sensitivity analysis study, scenarios were created by changing the weights of the criteria under the dimensions. In Table 14, the alternative ranking created as a result of 21 different scenarios were shown and the results were compared. As a result of the assessments, it was seen that the order did not change, the order remained the same. The rankings created as a result of the scenarios are seen in Figure 3. In this figure, the scores of alternatives in 21 different scenarios were illustrated (Scores on x axis, scenarios and average on y axis).

Table 14. Comparing the results

Scenarios	A ₁	A ₂	A ₃	A ₄	Ranking
S01	0.2347	0.2588	0.2635	0.2430	A ₃ > A ₂ > A ₄ > A ₁
S02	0.2365	0.2558	0.2650	0.2428	A ₃ > A ₂ > A ₄ > A ₁
S03	0.2344	0.2525	0.2702	0.2428	A ₃ > A ₂ > A ₄ > A ₁
S04	0.2347	0.2550	0.2686	0.2418	A ₃ > A ₂ > A ₄ > A ₁
S05	0.2363	0.2549	0.2653	0.2435	A ₃ > A ₂ > A ₄ > A ₁
S06	0.2370	0.2598	0.2622	0.2410	A ₃ > A ₂ > A ₄ > A ₁
S07	0.2362	0.2589	0.2632	0.2417	A ₃ > A ₂ > A ₄ > A ₁
S08	0.2358	0.2609	0.2664	0.2369	A ₃ > A ₂ > A ₄ > A ₁
S09	0.2391	0.2529	0.2659	0.2422	A ₃ > A ₂ > A ₄ > A ₁
S10	0.2254	0.2710	0.2603	0.2433	A ₂ > A ₃ > A ₄ > A ₁
S11	0.2422	0.2509	0.2709	0.2360	A ₃ > A ₂ > A ₁ > A ₄

S12	0.2430	0.2532	0.2663	0.2376	$A_3 > A_2 > A_1 > A_4$
S13	0.2399	0.2546	0.2727	0.2328	$A_3 > A_2 > A_1 > A_4$
S14	0.2420	0.2579	0.2718	0.2283	$A_3 > A_2 > A_1 > A_4$
S15	0.2412	0.2542	0.2716	0.2330	$A_3 > A_2 > A_1 > A_4$
S16	0.2476	0.2551	0.2632	0.2341	$A_3 > A_2 > A_1 > A_4$
S17	0.2450	0.2487	0.2732	0.2330	$A_3 > A_2 > A_1 > A_4$
S18	0.2369	0.2718	0.2559	0.2354	$A_2 > A_3 > A_1 > A_4$
S19	0.2433	0.2497	0.2607	0.2463	$A_3 > A_2 > A_4 > A_1$
S20	0.2391	0.2571	0.2690	0.2348	$A_3 > A_2 > A_1 > A_4$
S21	0.2367	0.2609	0.2539	0.2485	$A_2 > A_3 > A_4 > A_1$
Average	0.2384	0.2569	0.2657	0.2390	$A_3 > A_2 > A_4 > A_1$

Fig. 3. Rankings resulting from the scenarios

5. Conclusion

Businesses encounter many difficulties when selecting supplier to be a part of their supply chains. In order to overcome these difficulties, a supplier selection application was conducted in the study using two MCDM methods holistically. The topics considered by a plastic product manufacturer selected as the application subject during the selection process were collected in three dimensions as, green, agility and Industry 4.0. Triangular fuzzy numbers were preferred in order to reflect DM opinions appropriately.

According to the fuzzy SWARA method used in determining the weights of dimensions and criteria, the most important dimension is the agility dimension. The most important criteria are delivery speed, the usage of Industry 4.0 technologies and delivery flexibility, respectively. This situation shows that the businesses in the plastic product market find it important to establish agile supply chains. In order to ensure fast response, which is one of the most important benefits

of the agile supply chain, the supplier must have high delivery speed and the flexibility to adapt to the changing conditions. In this sense, it seems that the results are consistent. It was seen that the second most important criteria was the usage of Industry 4.0 technologies. It was observed that the business was aware of the advantages that the Industry 4.0 technologies provide. The other criteria in the Industry 4.0 dimension having relatively low scores suggest that the business perceives Industry 4.0 transformation mostly as involving technological advancements into processes. The criteria with the highest weights in the green dimension ranking last were reverse logistics, pollution control and green image. The business has high capability in terms of reverse logistics, is able to manage the pollution it causes and has a tendency to choose suppliers that will contribute to the green image of the business. It is seen that the suppliers should make an effort to prevent the damage that the plastic product in question causes to nature and recycle it.

The results found at the end of the methodology application were compared to the results of other studies in the literature. In a study they conducted on agile supplier selection, Beikhhakhian et al. (2015) found the most important criteria as delivery speed, cost minimization and price, respectively. Similarly, delivery speed had a weight result that was quite high among the 10 criteria evaluated. Sachdeva et al. (2019) found that for an automobile manufacturer in India, the usage of Industry 4.0 technologies was the highest among the five criteria considered in the supplier selection to compete in the Industry 4.0 era. In this study, the same criteria was ranked in second place with a high weight value once again. Matawale et al. (2016) found resource flexibility as the most important criteria in the agile supplier selection application; Dursun (2017) found that resource flexibility was one of the criteria with the highest conversion weight value in an agile supplier selection study. In this study, the same criteria was in fourth place in the weight result ranking. When this study is evaluated together with the aforementioned studies, it is possible to say that the criteria weight ranking is consistent.

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According to the result of the BWM method used in the evaluation of suppliers, the alternative A_3 was found to be the alternative with the highest value. A_4 and A_1 followed A_2 , which was in second place. The average of the results from the 21 scenarios created displayed that the ranking did not change.

It is thought that it would be appropriate to increase the number of DMs in order to expand the scope of the application in future studies. Increasing the number of evaluation dimensions and criteria, along with the number of alternative suppliers, are among changes that could be done to broaden the scope. In addition to the methods used and triangular fuzzy numbers; it would be possible to make comparisons between results through using gray numbers, Z-numbers etc. with other MCDM methods in the literature.

Declarations

Compliance with Ethical Standards

Ethical approval: This article does not contain any studies with human participants or animals performed.

The authors did not receive support from any organization for this study.

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

Informed Consent: Not applicable.

Authorship contributions

Authors contributed equally to this work.

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Appendices

Table 15. Calculation of weights of dimensions based on DM evaluations

DM ₁ order	D _n	Variable	s _j	k _j	q _j	w _j
1	D ₂	-	-	(1, 1, 1)	(1, 1, 1)	(0.4405, 0.4615, 0.4929)
2	D ₁	LI	(2/5, 1/2, 2/3)	(7/5, 3/2, 5/3)	(0.6000, 0.6667, 0.7142)	(0.2643, 0.3077, 0.3521)
3	D ₃	VI	(2/7, 1/3, 2/5)	(9/7, 4/3, 7/5)	(0.4285, 0.5000, 0.5556)	(0.1888, 0.2307, 0.2738)
DM ₂ order	D _n	Variable	s _j	k _j	q _j	w _j
1	D ₂	-	-	(1, 1, 1)	(1, 1, 1)	(0.5102, 0.5714, 0.6410)
2	D ₃	MI	(2/3, 1, 3/2)	(5/3, 2, 5/2)	(0.4000, 0.5000, 0.6000)	(0.2040, 0.2857, 0.3846)
3	D ₁	MI	(2/3, 1, 3/2)	(5/3, 2, 5/2)	(0.1600, 0.2500, 0.3600)	(0.0816, 0.1428, 0.2307)
DM ₃ order	D _n	Variable	s _j	k _j	q _j	w _j
1	D ₃	-	-	(1, 1, 1)	(1, 1, 1)	(0.4162, 0.4285, 0.4455)
2	D ₁	ML	(2/9, 1/4, 2/7)	(11/9, 5/4, 9/7)	(0.7778, 0.8000, 0.8181)	(0.3237, 0.3428, 0.3645)
3	D ₂	LI	(2/5, 1/2, 2/3)	(7/5, 3/2, 5/3)	(0.4666, 0.5334, 0.5844)	(0.1942, 0.2285, 0.2603)

Table 16. Calculation of the weights of green dimension criteria according to DM₁'s evaluations

Order	C _{1n}	Variable	s _j	k _j	q _j	w _j
1	C ₁₅	-	-	(1, 1, 1)	(1, 1, 1)	(0.3211, 0.3627, 0.4183)
2	C ₁₄	LI	(2/5, 1/2, 2/3)	(7/5, 3/2, 5/3)	(0.6000, 0.6667, 0.7142)	(0.1927, 0.2418, 0.2988)
3	C ₁₁	LI	(2/5, 1/2, 2/3)	(7/5, 3/2, 5/3)	(0.3600, 0.4444, 0.5102)	(0.1156, 0.1612, 0.2134)
4	C ₁₂	VI	(2/7, 1/3, 2/5)	(9/7, 4/3, 7/5)	(0.2571, 0.3333, 0.3968)	(0.0826, 0.1209, 0.1660)

5	C ₁₃	MI	(2/3, 1, 3/2)	(5/3, 2, 5/2)	(0.1028, 0.1667, 0.2381)	(0.0330, 0.0604, 0.0996)
6	C ₁₇	MI	(2/3, 1, 3/2)	(5/3, 2, 5/2)	(0.0411, 0.0833, 0.1428)	(0.0132, 0.0302, 0.0597)
7	C ₁₆	VI	(2/7, 1/3, 2/5)	(9/7, 4/3, 7/5)	(0.0293, 0.0625, 0.1111)	(0.0094, 0.0226, 0.0464)

Table 17. The best and worst alternatives against the criteria according to DM's evaluations

DM ₁			DM ₂			DM ₃		
Criteria	Best	Worst	Criteria	Best	Worst	Criteria	Best	Worst
C ₁₁	A ₂	A ₄	C ₁₁	A ₂	A ₁	C ₁₁	A ₂	A ₄
C ₁₂	A ₃	A ₄	C ₁₂	A ₂	A ₁	C ₁₂	A ₂	A ₄
C ₁₃	A ₃	A ₄	C ₁₃	A ₃	A ₄	C ₁₃	A ₂	A ₁
C ₁₄	A ₂	A ₁	C ₁₄	A ₂	A ₄	C ₁₄	A ₃	A ₁
C ₁₅	A ₂	A ₄	C ₁₅	A ₃	A ₄	C ₁₅	A ₂	A ₁
C ₁₆	A ₁	A ₃	C ₁₆	A ₃	A ₂	C ₁₆	A ₂	A ₄
C ₁₇	A ₃	A ₁	C ₁₇	A ₃	A ₁	C ₁₇	A ₃	A ₄
C ₂₁	A ₄	A ₂	C ₂₁	A ₁	A ₄	C ₂₁	A ₄	A ₂
C ₂₂	A ₁	A ₃	C ₂₂	A ₄	A ₂	C ₂₂	A ₁	A ₃
C ₂₃	A ₁	A ₃	C ₂₃	A ₁	A ₃	C ₂₃	A ₁	A ₃
C ₂₄	A ₄	A ₂	C ₂₄	A ₁	A ₂	C ₂₄	A ₁	A ₂
C ₂₅	A ₄	A ₃	C ₂₅	A ₁	A ₂	C ₂₅	A ₁	A ₂
C ₂₆	A ₄	A ₃	C ₂₆	A ₄	A ₃	C ₂₆	A ₂	A ₃
C ₂₇	A ₄	A ₂	C ₂₇	A ₁	A ₃	C ₂₇	A ₂	A ₄
C ₃₁	A ₃	A ₁	C ₃₁	A ₂	A ₁	C ₃₁	A ₄	A ₁
C ₃₂	A ₂	A ₁	C ₃₂	A ₂	A ₁	C ₃₂	A ₂	A ₄
C ₃₃	A ₃	A ₁	C ₃₃	A ₃	A ₄	C ₃₃	A ₂	A ₃
C ₃₄	A ₃	A ₂	C ₃₄	A ₂	A ₄	C ₃₄	A ₃	A ₁
C ₃₅	A ₂	A ₁	C ₃₅	A ₃	A ₄	C ₃₅	A ₂	A ₄
C ₃₆	A ₄	A ₁	C ₃₆	A ₄	A ₁	C ₃₆	A ₃	A ₄
C ₃₇	A ₃	A ₁	C ₃₇	A ₃	A ₄	C ₃₇	A ₂	A ₁

Table 18. Linguistic evaluations in BO and OW vector created against C₁₂

	Alternatives/DM	DM ₁	DM ₂	DM ₃
BO vector	A ₁	FIM	VIM	VIM
	A ₂	VIM	EIM	EIM
	A ₃	EIM	FIM	VIM
	A ₄	AIM	VIM	AIM
OW vector	A ₁	FIM	EIM	VIM
	A ₂	FIM	VIM	AIM
	A ₃	AIM	FIM	FIM
	A ₄	EIM	FIM	EIM

Table 19. Determining crisp number equivalents in BO and OW vectors created against C_{12}

		DM ₁		DM ₂		DM ₃	
		Fuzzy number	Crisp number	Fuzzy number	Crisp number	Fuzzy number	Crisp number
BO	A ₁	(3/2, 2, 5/2)	2	(5/2, 3, 7/2)	3	(5/2, 3, 7/2)	3
	A ₂	(5/2, 3, 7/2)	3	(1, 1, 1)	1	(1, 1, 1)	1
	A ₃	(1, 1, 1)	1	(3/2, 2, 5/2)	2	(5/2, 3, 7/2)	3
	A ₄	(7/2, 4, 9/2)	4	(5/2, 3, 7/2)	3	(7/2, 4, 9/2)	4
OW	A ₁	(3/2, 2, 5/2)	2	(1, 1, 1)	1	(5/2, 3, 7/2)	3
	A ₂	(3/2, 2, 5/2)	2	(5/2, 3, 7/2)	3	(7/2, 4, 9/2)	4
	A ₃	(7/2, 4, 9/2)	4	(3/2, 2, 5/2)	2	(3/2, 2, 5/2)	2
	A ₄	(1, 1, 1)	1	(3/2, 2, 5/2)	2	(1, 1, 1)	1

Table 20. Evaluation results of alternatives, ξ^* values and consistency ratios according to each DM

DM ₁							DM ₂						DM ₃					
C _{nn}	A ₁	A ₂	A ₃	A ₄	ξ^*	$\xi^*/CI=CR$	A ₁	A ₂	A ₃	A ₄	ξ^*	CR	A ₁	A ₂	A ₃	A ₄	ξ^*	CR
C ₁₁	0.2483	0.4379	0.1897	0.1241	0.0586	0.0073	0.1269	0.3654	0.3013	0.2064	0.0474	0.0071	0.1805	0.4774	0.2068	0.1353	0.0639	0.0079
C ₁₂	0.2553	0.1702	0.4681	0.1064	0.0426	0.0053	0.1235	0.4444	0.2593	0.1728	0.0741	0.0111	0.2000	0.5000	0.2000	0.1000	0.1000	0.0124
C ₁₃	0.2000	0.2000	0.5000	0.1000	0.1000	0.0124	0.2553	0.1702	0.4681	0.1064	0.0426	0.0053	0.0952	0.4286	0.2381	0.2381	0.0476	0.0059
C ₁₄	0.1525	0.3635	0.2552	0.2288	0.0942	0.0141	0.2381	0.4286	0.2381	0.0952	0.0476	0.0059	0.1241	0.2483	0.4759	0.1517	0.0207	0.0026
C ₁₅	0.3273	0.3727	0.2000	0.1000	0.0273	0.0034	0.1805	0.2707	0.4135	0.1353	0.1278	0.0159	0.1032	0.3809	0.2302	0.2857	0.0794	0.0099
C ₁₆	0.3809	0.2302	0.1032	0.2857	0.0794	0.0099	0.3003	0.0957	0.4258	0.1782	0.1089	0.0135	0.2483	0.4379	0.1897	0.1241	0.0586	0.0073
C ₁₇	0.1000	0.2000	0.5000	0.2000	0.1000	0.0124	0.1111	0.2909	0.3758	0.2222	0.0687	0.0085	0.1805	0.2707	0.4135	0.1353	0.1278	0.0159
C ₂₁	0.2288	0.1525	0.2552	0.3635	0.0942	0.0141	0.3758	0.2909	0.2222	0.1111	0.0687	0.0085	0.2031	0.1016	0.3849	0.3104	0.0959	0.0119
C ₂₂	0.3541	0.2486	0.1486	0.2486	0.0917	0.0137	0.2018	0.1579	0.2018	0.4386	0.0351	0.0052	0.3815	0.3146	0.0884	0.2155	0.0495	0.0062
C ₂₃	0.3635	0.2552	0.1525	0.2288	0.0942	0.0141	0.3541	0.2486	0.1486	0.2486	0.0917	0.0137	0.3703	0.1603	0.1050	0.3644	0.0496	0.0062
C ₂₄	0.2581	0.1098	0.1870	0.4451	0.0711	0.0088	0.3793	0.1241	0.2483	0.2483	0.1172	0.0146	0.4286	0.0952	0.2381	0.2381	0.0476	0.0059
C ₂₅	0.2909	0.2222	0.1111	0.3758	0.0687	0.0085	0.5000	0.1000	0.2000	0.2000	0.1000	0.0124	0.3104	0.1016	0.3849	0.2031	0.0959	0.0119
C ₂₆	0.2727	0.1818	0.0909	0.4545	0.0909	0.0113	0.2483	0.2483	0.1241	0.3793	0.1172	0.0146	0.2044	0.4972	0.0994	0.1989	0.0994	0.0124
C ₂₇	0.3408	0.0942	0.2466	0.3185	0.0582	0.0072	0.4297	0.1927	0.1406	0.2370	0.0443	0.0066	0.2483	0.3793	0.2483	0.1241	0.1172	0.0146
C ₃₁	0.1111	0.2222	0.3758	0.2909	0.0687	0.0085	0.0884	0.3815	0.2155	0.3146	0.0495	0.0062	0.1111	0.2222	0.2222	0.4444	0.0000	0.0000
C ₃₂	0.0833	0.4167	0.3333	0.1667	0.0833	0.0104	0.0957	0.4258	0.3003	0.1782	0.1089	0.0135	0.1833	0.3688	0.3118	0.1361	0.0396	0.0059
C ₃₃	0.1303	0.2180	0.3106	0.3411	0.0804	0.0120	0.2616	0.1628	0.4709	0.1047	0.0523	0.0065	0.2553	0.4681	0.1064	0.1702	0.0426	0.0053
C ₃₄	0.1818	0.0909	0.4545	0.2727	0.0909	0.0113	0.2258	0.4194	0.2258	0.1290	0.0323	0.0048	0.1111	0.2909	0.3758	0.2222	0.0687	0.0085
C ₃₅	0.1000	0.3727	0.3273	0.2000	0.0273	0.0034	0.2000	0.2000	0.5000	0.1000	0.1000	0.0124	0.2581	0.4451	0.1870	0.1098	0.0711	0.0088
C ₃₆	0.1579	0.2018	0.2018	0.4386	0.0351	0.0052	0.1000	0.2000	0.2000	0.5000	0.1000	0.0124	0.2483	0.2483	0.3793	0.1241	0.1172	0.0146
C ₃₇	0.1406	0.1927	0.4297	0.2370	0.0443	0.0066	0.2857	0.2302	0.3809	0.1032	0.0794	0.0099	0.1032	0.3809	0.2302	0.2857	0.0794	0.0099