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Smart and sustainable supplier selection using ınterval type-2 fuzzy AHP

Aralık tip-2 bulanık AHP yöntemi ile akıllı ve sürdürülebilir tedarikçi seçimi

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Smart and Sustainable Supplier Selection Using Interval Type-2 Fuzzy AHP

Highlights

- *It proposes a new model using Interval Type-2 Fuzzy AHP for the selection of smart and sustainable suppliers.*
- *It conducts the criteria-based supplier selection process that is effective on both smart and sustainable aspects.*
- *Supplier selection decision model based on AHP method with interval type-2 fuzzy sets enables more flexible and successful decision-making process in reflecting uncertainty.*
- *The applicability and effectiveness of the proposed approach are detailed in a case study on the evaluation of material suppliers for an automotive manufacturer.*
- *A comparative scenario analysis is performed to investigate the effect of different criteria and their priority weights under different conditions.*

Graphical Abstract

In this study, Interval Type-2 Fuzzy AHP method was proposed to evaluate the overall performance of suppliers. In order to demonstrate the applicability of the proposed method, an empirical study was conducted on the evaluation of material suppliers for an automotive manufacturer and a comparative scenario analysis was performed to investigate the effect of different smart and sustainable criteria under different conditions.

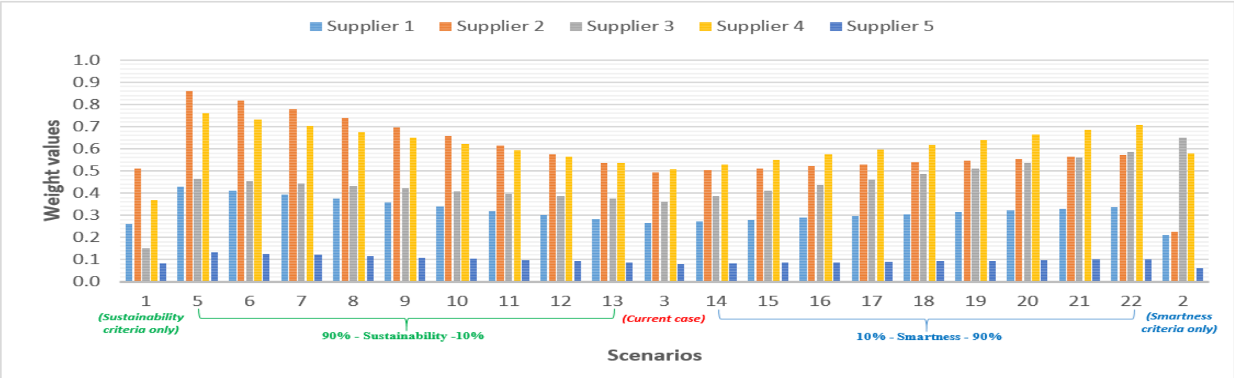

Figure. Performance changes of suppliers for all scenarios

Aim

The purpose of this paper is to propose a new model using Interval Interval Type-2 Fuzzy AHP for the selection of smart and sustainable suppliers.

Design & Methodology

Smart and sustainable supplier selection criteria are determined for evaluation process and employed AHP method with interval type-2 fuzzy sets to evaluate the overall performance of suppliers. Additionally, a comparative scenario analysis was performed to investigate the effect of different criteria under different conditions.

Originality

The originality of the manuscript lies in the criteria. Author(s) applied the method for supplier selection process based effective criteria on both smart and sustainable aspects. Even through, there are many different applications of FAHP in literature, to the best knowledge of the authors, this is the first study handling supplier selection with smart and sustainable criteria by using Interval Type-2 Fuzzy AHP.

Findings

Interval Type-2 Fuzzy AHP model is applied successfully and obtained more reliable results for smart and sustainable supplier selection decision of automotive industry.

Conclusion

The proposed model provides an effective framework to guide and direct decision makers for evaluating suppliers in the current competitive environment.

Declaration of Ethical Standards

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Smart and Sustainable Supplier Selection Using Interval Type-2 Fuzzy AHP

Araştırma Makalesi/Research Article

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ABSTRACT

Government regulations, customers' environmental awareness, quality of life-improving efforts and developments in the information and communication system have almost obliged organizations to consider smart and sustainable factors while evaluating their suppliers. Working with suitable suppliers in terms of technological, environmental and social aspects as well as economic aspects, will be the basis for smart and sustainable supply chains. An effective supplier selection running is also needed to continue the process in harmony. The issue of supplier selection is one of the multi-criteria decision-making problems that requires consideration of many qualitative and/or quantitative factors. In this study, Analytic hierarchy process (AHP) method with interval type-2 fuzzy sets, which are more flexible and successful in reflecting uncertainty for fuzzy decision-making problems with contradictory criteria, was proposed to evaluate the overall performance of suppliers. In order to demonstrate the applicability of the proposed method, an empirical study was conducted on the evaluation of material suppliers for an automotive manufacturer and a comparative scenario analysis was performed to investigate the effect of different criteria under different conditions.

Keywords: Interval type-2 fuzzy sets, interval type-2 fuzzy AHP, smart, sustainable, supplier selection.

Aralık Tip-2 Bulanık AHP Yöntemi ile Akıllı ve Sürdürülebilir Tedarikçi Seçimi

ÖZ

Devlet düzenlemeleri, müşterilerin çevre bilinci, yaşam kalitesini iyileştirme çabaları ve bilgi ve iletişim sistemindeki gelişmeler, kuruluşları tedarikçilerini değerlendirirken akıllı ve sürdürülebilir faktörleri göz önünde bulundurmak zorunda bırakmıştır. Ekonomik olduğu kadar teknolojik, çevresel ve sosyal açılardan da uygun tedarikçilerle çalışmak, akıllı ve sürdürülebilir tedarik zincirlerinin temelini oluşturacaktır. Sürecin uyum içinde devam etmesi için etkin bir tedarikçi seçimi çalışması da gereklidir. Tedarikçi seçimi konusu, birçok nitel ve/veya nicel faktörün dikkate alınmasını gerektiren çok kriterli karar verme problemlerinden biridir. Bu çalışmada, tedarikçilerin genel performansını değerlendirmek için, çelişkili kriterlere sahip bulanık karar verme problemleri için belirsizliği yansıtmada daha esnek ve başarılı olan aralıklı tip-2 bulanık kümeli AHP yöntemi önerilmiştir. Önerilen yöntemin uygulanabilirliğini göstermek için bir otomotiv üreticisi için malzeme tedarikçilerinin değerlendirilmesi üzerine ampirik bir çalışma yapılmış ve farklı koşullar altında farklı kriterlerin etkisini görmek için karşılaştırmalı bir senaryo analizi yapılmıştır.

Anahtar Kelimeler: Aralık tip-2 bulanık kümeler, aralık tip-2 bulanık AHP, akıllı, sürdürülebilir, tedarikçi seçimi.

1. INTRODUCTION

The growing requirement and significance of sustainability has become more apparent in the last few decades, with defending rights such as social development, equality and security as well as increasing effects of climate change, decreasing resources, environmental awareness of the communities, legal regulations and profit margins. Sustainability is characterized as using the resources correctly to meet needs of today without compromising the possibilities to meet the needs of posterity. Within the context of supply chain management, sustainability has been mentioned using a series of phrases in the literature. While the first initiatives of sustainability tend to concentrate on environmental issues, in the process of time, triple bottom line (economic, environmental and social) approach has been adopted for sustainability [1]. Accordingly, companies try to choose sustainable suppliers to improve their sustainability profiles.

New tools in information and communication, organization and logistics have led to the development of new production techniques and new business models in the modern business world. Along with these developments, changes in the market have caused the abandonment of classical production methods and the emergence of new requirements [2]. Therefore, businesses are trying to adapt to new technologies and approaches in order to meet increasing customer needs and expectations and to be competitive. These

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technologies, running to the aid of enterprises, first appeared under the name of Industry 4.0. The integration of digitalization and the Internet into production processes has also led to a global transformation in supply chain management and has revealed the concept of smart supply chain. The future supply chains are reshaped by connecting all members with structures such as smart suppliers, smart factories, smart processes, smart logistics and smart products. A fully automated, integrated and optimized production flow is ensured among suppliers, manufacturers and end customers by reconstructing manufacturing processes with Industry 4.0 technologies such as Internet of Things, RFID, Cyber-Physical Systems, Robot Technology, Artificial Intelligence, Block chain Technology, Cloud Information Systems, Big Data, Cyber Security, Digital Production and Augmented Reality. As a result, working with both smart and sustainable suppliers will provide returns such as reducing costs, increasing profitability, flexibility, efficiency, launching products in less time, increasing corporate reputation, high customer satisfaction, high motivation and competitive advantage.

1.1. Smart and Sustainable Supplier Selection

Many businesses already receive support from supplier companies in purchasing products, services, or the realization of auxiliary processes. No matter what sector you are in, the golden key of trade is to work with the right supplier. After determining the suitable suppliers and collecting information about them, the enterprises evaluate the potential suppliers according to the criteria they have determined. The criteria may vary according to purpose and the product to be supplied and should be defined accordingly. While there were only a few criteria sought, such as reasonable price and close distance in the past, supplier selection has become a process on its own, and the criteria sought in suppliers have increased.

For example, due to the increasing awareness of environmental and social issues, companies have started to focus on sustainability when evaluating suppliers to ensure sustainable supply chain management. The sustainable supplier selection problem could be described as the classical supplier selection problem that considers environmental, economic, and social criteria to choose and track supplier performance [3]. Therefore, sustainable supply chain management practices could be described as basic criteria and easily operated for sustainable supplier selection [4, 5].

Apart from that, with Industry 4.0, businesses are also aware that it is more difficult to improve performance in traditional ways and the need to develop newer solutions resulting from technological innovations. In this direction, they try to benefit from advanced intelligent technologies in the entire supply chain, from purchasing to distribution, to remain competitive. Because smart supply chain applications make it possible to collect large amounts of information and use it to increase efficiency and support faster response to customer expectations [6]. The first stage of this system is smart supplier selection. Accordingly, organizations can be employed innovative technology tools as evaluating criteria when choosing smart suppliers to improve their technological development.

1.2. Brief Review of the Literature

Due to its simplicity and flexibility, interval type-2 fuzzy AHP (IT-2 FAHP) is applied as a mechanism to select the best alternative solution for decision-making problems in many application areas such as logistics, health, energy, investment, and risk management. It is also widely preferred among hybrid approaches by integrating with other methods and is applied to weight the criteria of decision-making problems [7].

One of the first studies of IT-2 FAHP, Kahraman et al. [8] developed an IT-2 FAHP method along with a new ranking approach for type-2 fuzzy sets. They demonstrated the potential applicability of the method on a supplier selection problem. Cevik Onar et al. [9] proposed hybrid approach integrating IT-2 FAHP with hesitant FTOPSIS for strategic decisions selection problem of a multinational consumer electronics company. Oztaysi [10] developed a group decision making methodology using IT-2 FAHP for Enterprise Information Systems Project Selection problem. Kilic and Kaya [11] proposed a decision approach composed of type-2 FAHP and type-2 FTOPSIS for investment projects evaluation problems of development agencies operating in Turkey. Gul et al. [12] proposed an integration of computer simulation, IT-2 FAHP and ELECTRE for the emergency department system of a university hospital. Balin and Baraçli [13] used both IT-2 FAHP and IT-2 FTOPSIS together to determine the best renewable energy alternatives for Turkey. Soner et al. [14] proposed hybrid approach integrates AHP into VIKOR technique under interval type-2 fuzzy environment to provide a practical application in maritime transportation industry. Ayodele et al. [15] proposed a geographic information system-based model for wind farm site selection using IT-2 FAHP and implemented the model to determine the convenient wind farm sites in Nigeria. Celik and Akyuz [16] presented a comprehensive method incorporates AHP and TOPSIS extended by interval type-2 fuzzy sets for selecting suitable ship loader type in maritime transportation. Yilmaz et al. [17] proposed a three-stage holistic approach combining IT-2 FAHP and Data envelopment analysis (DEA) to evaluate the performance of real estate investment trusts in Turkey for Borsa Istanbul. Kiracı and Akan [18] used a hybrid method composed of IT-2 FAHP and IT-2 FTOPSIS for multi-dimensional evaluation and selection of the most suitable commercial aircraft alternatives. Meniz et al. [19] developed a new multilevel type-2 fuzzy AHP method expanded by adding sub-criteria to IT-2 FAHP method and applied proposed method to a portfolio selection problem. Atıcı et al. [20] utilized interval type-2 fuzzy Analytical

Hierarchy Process for evaluations of e-learning platforms by comparing their critical success factors.

Nowadays, the selection of Smart and Sustainable Suppliers has emerged as an important decision for companies that want to develop their competitiveness and exhibit sustainable performance with the help of the developing technologies of the Industry 4.0 era in their markets. However, these two paradigms have been generally dealt with separately by researchers, and there has not been much study done under the name of "smart and sustainable supplier selection".

Practitioners and researchers focus more attention on sustainable supplier selection [21]. Chiouy et al. [22] prioritized 15 various evaluation criteria on environmental, economic and social performance for sustainable supplier selection in the Taiwanese electronics industry by FAHP method. Azadnia et al. [23] suggested an approach integrated for clustering and selecting sustainable suppliers for a manufacturing firm in Iran automotive industry. They used self- organizing map to cluster suppliers, FAHP to determine the sustainable criteria weights (Economic: cost, quality, delivery; Environmental: pollution, environmental management system, environment friendly product design; and Social: the rights of stakeholders, occupational health-safety management systems) and Technique for order of preference by similarity to ideal solution (TOPSIS) to choose the best cluster of suppliers and the best supplier of them. Gold and Awasthi [24] proposed a two-stage FAHP methodology for global sustainable supplier selection that considers risks of sustainability from sub-suppliers too. In attempt to evaluate the suppliers, they determined 25 criteria under five different categories; Economic, Environmental, Social, Quality of relationship, Global risks. Fallahpour et al. [25] determined the most critical 13 criteria with 46 sub-criteria in each of the directions of triple bottom line (TBL) for sustainable supplier selection via a survey, Fuzzy Preference Programming and FTOPSIS for identifying the best supplier. Zhou and Xu [26] proposed an integrated decision making approach Decision-making trial and evaluation laboratory-Analytic network process-Fuzzy Multi criteria optimization and compromise solution (DEMATEL-ANP-FVIKOR) based on hybrid information aggregation and determined six aspects: Operational Agreement, Corporate Reputation, Product Advantage, Green Impact, Service Capability and Social Responsibility and 24 sub-criteria considering the trade-offs between Economic, environmental and societal objectives for sustainable supplier selection. Kannan et al. [27] combined interval VIKOR and fuzzy Best Worst Method (BWM) in the circular supply chains for evaluating and prioritizing sustainable suppliers. Evaluation criteria are classified into three categories of social, economic and circular factors and evaluate six suppliers in Iran wire-cable industry.

Smart supply chain management-supplier selection is a hot topic worldwide, attracting the attention of many global industries. Academic studies on smart supply chain management, in which one or more of Industry 4.0 technologies are integrated, have also been observed in recent years.

Ghadimi et al. [28] suggested a Multi-Agent Systems approach to address intelligent sustainable supplier selection procedure for Industry 4.0 supply chains. They approved the technical capability for smartness, while considering the three dimensions of TBL for sustainability to evaluate suppliers. Chen et al. [4] proposed a hybrid rough-fuzzy DEMATEL-TOPSIS methodology to sustainable supplier selection for a smart supply chain. They determined 14 criteria under economic, environmental and social practices. Hasan et al. [29] developed a Decision Support System, which aid the decision maker for incorporating and processing such imprecise heterogeneous data in a united framework and used FTOPSIS to rank resilient suppliers in a logistic 4.0 environment. When evaluating suppliers, they took into account smartness criteria such as Digitalization, Traceability, e-engineering, Automation disruption and Cyber security risk management.

Table 1 summarizes evaluation paradigm, solution method, type of fuzziness, application type / area of papers on smart/sustainable supplier selection problems obtained from the literature in recent years.

The remainder of this paper is organized as follows: The following section introduces IT-2 Fuzzy AHP methodology with primary definitions of T-2 fuzzy sets. Section 3 provides a case study on the evaluation of material suppliers for an automotive manufacturer. Section 4 performs a comparative scenario analysis to identify the effect of different criteria and their priority weights on supplier selection with suggested method. Finally, conclusions of the study with suggestions for future works are presented in Section 5.

Table 1. Review of articles on smart and/or sustainable supplier selection

		Evaluation paradigm		Solution method		Type of fuzziness						Application type / area		
No	**Author(s)**	**Smart**	**Sustainable**	**MCDM**	**Others**	**Type-1**	**Type-2**	**Interval**	**Intuitionistic**	**Pythagorean**	**Rough**	**Real Case**	**Hypothetical**	**Area**
1	Chiouy et al. [22]		✓	FAHP		✓						✓		Taiwanese electronics industry
2	Büyüközkan and Çifçi [30]		✓	FANP		✓						✓		A main producer of a Turkish white goods industry
3	Azadnia et al. [23]		✓	FAHP TOPSIS		✓						✓		Fuel filter suppliers for a manufacturing firm in Iran automotive industry
4	Dai and Blackhurst [31]		✓	AHP QFD									✓	An illustrative example of a large retailer
5	Wen et al. [32]		✓	FTOPSIS					✓				✓	An empirical study
6	Govindan et al. [33]		✓	FTOPSIS		✓							✓	A numerical example
7	Ghadimi and Heavey [34]		✓		Fuzzy Inference System	✓						✓		Medical Device Industry
8	Orji and Wei [35]		✓	FDEMATEL TOPSIS		✓						✓		A gear manufacturing company in China
9	Gold and Awasthi [24]		✓	FAHP		✓							✓	Global sustainable supplier selection problems observed by vulnerable to naming and shaming campaigns and civil society.
10	Azadi et al. [36]		✓	FDEA	Russell measure	✓						✓		A resin production company in Iran
11	Zhou et al. [37]		✓	FDEA	Russell measure		✓						✓	Numerical experiments
12	Fallahpour et al. [25]		✓	FAHP FTOPSIS	Fuzzy Preference Programming	✓						✓		Fibers, finishing and auxiliary materials suppliers for a knitted fabric manufacturer
13	Luthra et al. [38]		✓	AHP VIKOR								✓		A real world example of an automobile company in India
14	Zhou and Xu [26]		✓	DEMATEL ANP FVIKOR				✓				✓		A real case of a large supermarket
15	Kannan [39]		✓		Fuzzy Delphi Method							✓		Textile industry located in the emerging economy of India
16	Kafa et al. [40]		✓	FAHP FPROMETHEE FTOPSIS		✓						✓		A real light bulbs manufacturing company located in Île-de-France
17	Sen et al. [41]		✓	FTOPSIS, FMOORA FGRA					✓				✓	A case empirical illustration
18	Awasthi et al. [42]		✓	FAHP FVIKOR		✓							✓	A numerical application of an electronic goods manufacturing company
19	Xu et al. [43]		✓	FAHPSort II			✓	✓					✓	A numerical example of material suppliers
20	Liu et al. [44]		✓	FAHP FTOPSIS		✓						✓		An agrifood value chain application
21	Yu et al. [3]		✓	FTOPSIS				✓		✓		✓		A real-world case of a home appliances manufacturer in China
22	Wang et al. [45]		✓	FAHP TOPSIS		✓						✓		Thi Hien Joint Garment Stock Company in Vietnam's textile and garment industry
23	Ghadimi et al. [28]	✓	✓		Multi-Agent Systems							✓		A medical device manufacturer.
24	Chen et al. [4]	✓	✓	FDEMATEL FTOPSIS							✓	✓		A real case study of new Chinese energy vehicle transmission suppliers
25	Hasan et al. [29]	✓		FTOPSIS		✓							✓	A hypothetical case study that can be generalized for firms operating under Logistics 4.0
26	Ecer and Pamucar [46]		✓	F BWM FCoCoSo	Bonferroni functions	✓						✓		A real world example of Serbia home appliance manufacturer
27	Kannan et al. [27]		✓	F BWM IVIKOR		✓		✓				✓		Wire-and-cable industry in Iran
28	Stević et al. [47]		✓	MARCOS[1]								✓		Healthcare industry (in a polyclinic) in Bosnia and Herzegovina

[1] *MCDM (Multi Criteria Decision Making), AHP (Analytic hierarchy process), ANP (Analytic network process), BWM (*Best-Worst Method), *CoCoSo (Combined Compromise Solution), DEA (Data envelopment analysis), DEMATEL (Decision-making trial and evaluation laboratory), GRA(Grey relational analysis), MARCOS (Measurement of Alternatives and Ranking according to COmpromise Solution), MOORA (Multi-objective optimization by ratio analysis), PROMETHEE (Preference ranking organisation method for enrichment of evaluations), QFD (*Quality function deployment), *TOPSIS (Technique for order of preference by similarity to ideal solution), VIKOR (VIšeKriterijumska Optimizacija I Kompromisno Resenje – Multicriteria optimization and compromise solution).*

2. MATERIAL and METHOD

In this section, the methods we used in our study are summarized.

2.1. Interval Type-2 Fuzzy Sets

Fuzzy sets were designed by Lotfi A.[48] in 1965. This theory has been used for dealing with many problem-specific uncertainties and modeling decision-making processes by representing uncertainty mathematically [49-51]. However, in order to address the uncertainties caused by some deficiencies of classical fuzzy sets, Zadeh [52] proposed T-2 fuzzy clusters, their fuzzy sets membership values are fuzzy numbers too. While a membership degree of IT-1 FS is defined with a membership function, membership degrees of IT-2 FS are themselves fuzzy sets. They are quite helpful in situations in which it is hard to determine an accurate membership function for fuzzy sets. Therefore, if IT-1 FSs are considered as the first-rank approach to real-world uncertainties, IT-2 FSs could be seen as a second-rank approach to uncertainty. Hence, while membership functions of IT-1 FSs are two-dimensional, membership functions of T-2 fuzzy sets are three-dimensional, which provides supplemental degrees of freedom to model uncertainties directly [50]. However, because of its computational complexity, interval type-2 fuzzy sets (IT-2 FS) are used more than the general one. [53].

Some definitions of T-2 FS and IT-2 FS from Mendel et al. [53] and their basic arithmetic operations are given below [8, 53-55].

A T-2 FS $\tilde{\tilde{A}}$ in the universe of discourse X could be represented by a T-2 membership function $\mu_{\tilde{\tilde{A}}}$, displayed as follows:

$$\tilde{\tilde{A}} = \left\{\left((x,u), \mu_{\tilde{\tilde{A}}}(x,u)\right) \middle| \begin{matrix} \forall x \in X, \forall u \in J_x \subseteq [0,1], \\ 0 \le \mu_{\tilde{\tilde{A}}}(x,u) \le 1 \end{matrix} \right\}, \quad (1)$$

where J_x states an interval in [0, 1]. Moreover, T-2 FS $\tilde{\tilde{A}}$ also could be characterized as follows:

$$\tilde{\tilde{A}} = \int_{x\in X} \int_{u\in J_x} \mu_{\tilde{\tilde{A}}}(x,u)/(x,u), \quad (2)$$

where $J_x \subseteq [0,1]$ and $\iint$ states union overall acceptable x and u.

Let $\tilde{\tilde{A}}$ be a T-2 FS in the universe of discourse X represented by the T-2 membership function $\mu_{\tilde{\tilde{A}}}$. If all $\mu_{\tilde{\tilde{A}}}(x,u) = 1$, then $\tilde{\tilde{A}}$ is called an interval type-2 fuzzy set. An IT-2 FS $\tilde{\tilde{A}}$ could be declared as an especial case of a T-2 FS, represented as follows:

$$\tilde{\tilde{A}} = \int_{x\in X} \int_{u\in J_x} 1/(x,u), \quad (3)$$

where $J_x \subseteq [0,1]$.

The upper and lower membership functions of an IT-2 FS are T-1 membership functions, respectively. As seen in Figure 1, a trapezoidal IT-2 FS is represented as below:

$$\tilde{\tilde{A}}_i = (\tilde{A}_i^U, \tilde{A}_i^L) = \begin{pmatrix} (a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U;\ H_1(\tilde{A}_i^U), H_2(\tilde{A}_i^U)), \\ (a_{i1}^L, a_{i2}^L, a_{i3}^L, a_{i4}^L;\ H_1(\tilde{A}_i^L), H_2(\tilde{A}_i^L)) \end{pmatrix}$$

Where $\tilde{A}_i^U$ and $\tilde{A}_i^L$ are T-1 FSs, $a_{i1}^U, a_{i2}^U, a_{i3}^U, a_{i4}^U, a_{i1}^L, a_{i2}^L, a_{i3}^L$ and a_{i4}^L are the references points of the IT-2 FS $\tilde{A}_i^U$; $H_j(\tilde{A}_i^U)$ states the membership value of the element $a_{j(j+1)}^U$in the upper trapezoidal membership function $(\tilde{A}_i^U), 1 \le j \le 2, H_j(\tilde{A}_i^L)$ states the membership value of the element $a_{j(j+1)}^L$ in the lower trapezoidal membership function $\tilde{A}_i^L, 1 \le j \le 2, H_1(\tilde{A}_i^U) \in [0,1], H_2(\tilde{A}_i^U) \in [0,1]$, $H_1(\tilde{A}_i^L) \in [0,1]$, $H_2(\tilde{A}_i^L) \in [0,1]$ and $1 \le i \le n$.

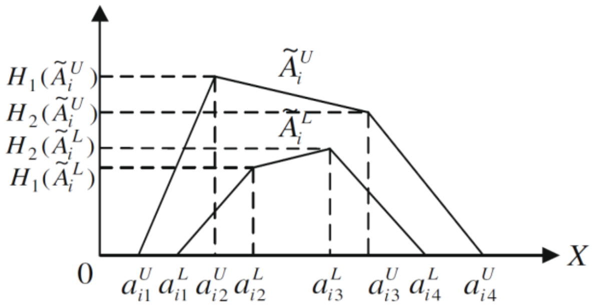


Figure 1. The upper trapezoidal membership function $\tilde{A}_i^U$ and the lower trapezoidal membership function $\tilde{A}_i^L$ of the IT-2 FS $\tilde{\tilde{A}}_i$

The basic arithmetic operations with trapezoidal IT-2 FSs are defined as follows.

Let $\tilde{\tilde{A}}_1$ and $\tilde{\tilde{A}}_2$ are IT-2 FSs and *k* is a crisp number;

Addition:

$$\tilde{\tilde{A}}_1 \oplus \tilde{\tilde{A}}_2 = (\tilde{A}_1^U, \tilde{A}_1^L) \oplus (\tilde{A}_2^U, \tilde{A}_2^L)$$
$$= \begin{pmatrix} (a_{11}^U + a_{21}^U, a_{12}^U + a_{22}^U, a_{13}^U + a_{23}^U, a_{14}^U + a_{24}^U; \\ \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U))), \\ (a_{11}^L + a_{21}^L, a_{12}^L + a_{22}^L, a_{13}^L + a_{23}^L, a_{14}^L + a_{24}^L; \\ \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L))) \end{pmatrix} (4)$$

Subtraction:

$$\tilde{\tilde{A}}_1 \ominus \tilde{\tilde{A}}_2 = (\tilde{A}_1^U, \tilde{A}_1^L) \ominus (\tilde{A}_2^U, \tilde{A}_2^L)$$
$$= \begin{pmatrix} (a_{11}^U - a_{24}^U, a_{12}^U - a_{23}^U, a_{13}^U - a_{22}^U, a_{14}^U - a_{21}^U; \\ \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U))), \\ (a_{11}^L - a_{24}^L, a_{12}^L - a_{23}^L, a_{13}^L - a_{22}^L, a_{14}^L - a_{21}^L; \\ \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L))) \end{pmatrix} (5)$$

Multiplication:

$$\tilde{\tilde{A}}_1 \otimes \tilde{\tilde{A}}_2 = (\tilde{A}_1^U, \tilde{A}_1^L) \otimes (\tilde{A}_2^U, \tilde{A}_2^L)$$
$$= \begin{pmatrix} (a_{11}^U \times a_{21}^U, a_{12}^U \times a_{22}^U, a_{13}^U \times a_{23}^U, a_{14}^U \times a_{24}^U; \\ \min(H_1(\tilde{A}_1^U), H_1(\tilde{A}_2^U)), \min(H_2(\tilde{A}_1^U), H_2(\tilde{A}_2^U))), \\ (a_{11}^L \times a_{21}^L, a_{12}^L \times a_{22}^L, a_{13}^L \times a_{23}^L, a_{14}^L \times a_{24}^L; \\ \min(H_1(\tilde{A}_1^L), H_1(\tilde{A}_2^L)), \min(H_2(\tilde{A}_1^L), H_2(\tilde{A}_2^L))) \end{pmatrix} (6)$$

Multiplication by a crisp number k:

$$k\tilde{\tilde{A}}_1=\left(\begin{pmatrix} k\times a_{11}^U, k\times a_{12}^U, k\times a_{13}^U, k\times a_{14}^U; \\ H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U) \end{pmatrix}, \begin{pmatrix} k\times a_{11}^L, k\times a_{12}^L, k\times a_{13}^L, k\times a_{14}^L; \\ H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L) \end{pmatrix}\right) \quad (7)$$

Division by a crisp number k:

$$\frac{\tilde{\tilde{A}}_1}{k}=\left(\begin{pmatrix} \frac{1}{k}\times a_{11}^U, \frac{1}{k}\times a_{12}^U, \frac{1}{k}\times a_{13}^U, \frac{1}{k}\times a_{14}^U; \\ H_1(\tilde{A}_1^U), H_2(\tilde{A}_1^U) \end{pmatrix}, \begin{pmatrix} \frac{1}{k}\times a_{11}^L, \frac{1}{k}\times a_{12}^L, \frac{1}{k}\times a_{13}^L, \frac{1}{k}\times a_{14}^L; \\ H_1(\tilde{A}_1^L), H_2(\tilde{A}_1^L) \end{pmatrix}\right), \text{where } k>0 \quad (8)$$

2.2. Interval Type-2 Fuzzy AHP

In the study, Kahraman et al. [8]'s IT-2 FAHP method, which regulated Buckley [56]'s T-1 fuzzy AHP method based on IT-2 FS, will be used. IT-2 FS theory would allow some degree of freedom to specify the high-level vagueness and uncertainty of real-life environments with the upper and lower membership functions. The steps of this method are summarized below [8].

Step 1: Describe the problem and define its goal.
Step 2: Establish the hierarchical structure of the problem including the criteria, sub-criteria and alternatives.
Step 3: Fuzzy binary comparison matrix is constructed among all criteria. Linguistic variables used by experts and their trapezoidal interval type-2 fuzzy scales to create the binary comparison matrix are given in Table 2. Fuzzy binary comparison matrices are created as follows (9) using linguistic variables.

$$\tilde{\tilde{A}}=\begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1n} \\ \tilde{\tilde{a}}_{21} & 1 & \cdots & \tilde{\tilde{a}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\tilde{a}}_{n1} & \tilde{\tilde{a}}_{n2} & \cdots & 1 \end{bmatrix}=\begin{bmatrix} 1 & \tilde{\tilde{a}}_{12} & \cdots & \tilde{\tilde{a}}_{1n} \\ 1/\tilde{\tilde{a}}_{12} & 1 & \cdots & \tilde{\tilde{a}}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ 1/\tilde{\tilde{a}}_{1n} & 1/\tilde{\tilde{a}}_{2n} & \cdots & 1 \end{bmatrix} \quad (9)$$

$$\text{Where } 1/\tilde{\tilde{a}}=\left(\left(\frac{1}{a_{14}^U},\frac{1}{a_{13}^U},\frac{1}{a_{12}^U},\frac{1}{a_{11}^U}; H_1(a_{12}^U), H_2(a_{13}^U)\right), \left(\frac{1}{a_{24}^L},\frac{1}{a_{23}^L},\frac{1}{a_{22}^L},\frac{1}{a_{21}^L}; H_1(a_{22}^L), H_2(a_{23}^L)\right)\right)$$

Step 4: All fuzzy pairwise comparison matrices are defuzzfied and consistency is examined. If inconsistency is found, experts are asked to re-evaluate. DTraT approach is used for defuzzification values of the fuzzy numbers.

Step 5: The geometric mean of each row $\tilde{\tilde{r}}_i$ is calculated and then the fuzzy weights are calculated by normalization.

$$\tilde{\tilde{r}}_i = [\tilde{\tilde{a}}_{i1}\otimes \dots \otimes \tilde{\tilde{a}}_{in}]^{1/n} \quad (10)$$

$$\text{Where, } \sqrt[n]{\tilde{\tilde{a}}_{ij}} = \left(\left(\sqrt[n]{a_{ij1}^U}, \sqrt[n]{a_{ij2}^U}, \sqrt[n]{a_{ij3}^U}, \sqrt[n]{a_{ij4}^U}; \mathrm{H}_1^{\mathrm{U}}(a_{ij}), \mathrm{H}_2^{\mathrm{U}}(a_{ij})\right), \left(\sqrt[n]{a_{ij1}^L}, \sqrt[n]{a_{ij2}^L}, \sqrt[n]{a_{ij3}^L}, \sqrt[n]{a_{ij4}^L}; \mathrm{H}_1^{\mathrm{L}}(a_{ij}), \mathrm{H}_2^{\mathrm{L}}(a_{ij})\right)\right) \quad (11)$$

Step 6: The fuzzy weights of each criterion are calculated. The fuzzy weight of the criterion i, $\tilde{\tilde{w}}_i$ is calculated as follows;

$$\tilde{\tilde{w}}_i = \tilde{\tilde{r}}_i \otimes [\tilde{\tilde{r}}_1 \oplus \dots \oplus \tilde{\tilde{r}}_i \oplus \dots \oplus \tilde{\tilde{r}}_n]^{-1} \quad (12)$$

$$\text{Where, } \frac{\tilde{\tilde{a}}_{ij}}{\tilde{\tilde{b}}_{ij}} = \left(\left(\frac{a_1^U}{b_4^U},\frac{a_2^U}{b_3^U},\frac{a_3^U}{b_2^U},\frac{a_4^U}{b_1^U}; min\left(H_1^U(a),H_1^U(b)\right), min\left(H_2^U(a),H_2^U(b)\right)\right), \left(\frac{a_1^L}{b_4^L},\frac{a_2^L}{b_3^L},\frac{a_3^L}{b_2^L},\frac{a_4^L}{b_1^L}; min\left(H_1^L(a),H_1^L(b)\right), min\left(H_2^L(a),H_2^L(b)\right)\right)\right) \quad (13)$$

Step 7: The fuzzy performance scores of each alternative are calculated.

$$\tilde{U}_i = \sum_{j=1}^{n} \tilde{\tilde{w}}_j \, \tilde{\tilde{r}}_{ij} \ , \forall i. \quad (14)$$

where $\tilde{U}_i$ is the fuzzy utility of alternative i, $\tilde{\tilde{w}}_j$ is the weight of the criterion j, and $\tilde{\tilde{r}}_{ij}$ is the score of the alternative i with respect to criterion j.

Step 8: The interval type-2 fuzzy sets are defuzzified in order to determine the importance ranking of the alternatives and the classical AHP method's procedure is applied to determine the best alternative. The DTraT method is used for defuzzification in this step.

$$DTraT = \frac{\left[\frac{(u_U-l_U)+(\beta_U.m_{1U}-l_U)+(\alpha_U.m_{2U}-l_U)}{4}+l_U\right]+\left[\frac{(u_L-l_L)+(\beta_L.m_{1L}-l_L)+(\alpha_L.m_{2L}-l_L)}{4}+l_L\right]}{2} \quad (15)$$

Table 2. Linguistic variables and their interval type-2 fuzzy scales [8]

Linguistic variables	Trapezoidal interval type-2 fuzzy scales
Absolutely Strong (AS)	(7,8,9,9;1,1) (7.2,8.2,8.8,9;0.8,0.8)
Very Strong (VS)	(5,6,8,9;1,1) (5.2,6.2,7.8,8.8;0.8,0.8)
Fairly Strong (FS)	(3,4,6,7;1,1) (3.2,4.2,5.8,6.8;0.8,0.8)
Slightly Strong (SS)	(1,2,4,5;1,1) (1.2,2.2,3.8,4.8;0.8,0.8)
Exactly Equal (E)	(1,1,1,1;1,1) (1,1,1,1;1,1)
If factor i has one of the above linguistic variables assigned to it when compared with factor j, then j has the reciprocal value when compared with i	

3. A CASE STUDY

In this section, a smart and sustainable supplier selection problem for an automotive manufacturer in Turkey is used to indicate the feasibility of the proposed method. Due to the privacy policy of the anonymous company, its name and some data in the case study have been reported by changing here.

X Truck Factory, which has been manufacturing world-class trucks for over 20 years offers services to over 58 countries including Turkey. It has a covered area of 105.000 m2 built on a total of 452.000 m² of land. This company, contains facilities equipped with modern production robots and quality measurement laboratories equipped with latest equipment, aims to identify the best supplier for its new model heavy-truck parts. Some of these parts are given in Figure 2. For this, the company decided to work with suppliers with innovative technologies and sustainable norms. After preliminary screening, directors of company identified five potential suppliers for further evaluation. Suppliers will be evaluated on two main factors; smart and sustainable maturity levels that are important for the company.

The concept of smartness includes artificial intelligence, sensors, cyber physical systems, Internet of things, robotics technologies, big data, cloud computing and cyber security that come with Industry 4.0 age. In order to analyze the smartness level of suppliers, their strategies, culture, customers, products, operations and technology performances should be examined. The concept of sustainability is a holistic approach that includes economic, environmental and social dimensions.

As a result, five criteria to be regarded in the evaluation process were determined as C1: Economic Capabilities, C2: Environmental Performance, C3: Social Responsibility, C4: Manufacturing Technology Based Smart Tools, C5: Business Management Based Smart Operations as seen in Table 3.

The decision-makers, the company's general manager and senior executives responsible for finance, marketing, and production, define the evaluation of criteria and alternatives with linguistic variables. These evaluations were determined by the common opinions of the decision-makers in consultation. Using the scale of linguistic variables given in Table 2, experts obtained pair-wise comparison matrices shown in Table 4 and Table 5 by comparing the criteria and evaluating the alternatives under each criterion.

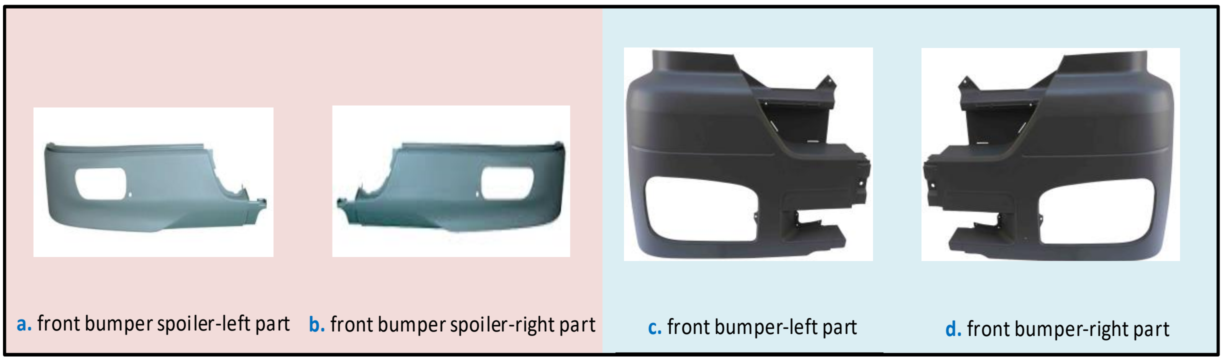


Figure 2. Some figures of truck parts supplied from potential suppliers

Table 3. Smart and Sustainable supplier selection criteria with their primary items

	No	Criteria Name	Code	Primary Items
Sustainability	1	**Economic Capabilities**	**C1**	Price, Cost, Quality, Delivery, Service
	2	**Environmental Performance**	**C2**	Environmental Management, ISO 14000, CO_2 Emissions, Energy Consumption, Pollution Reduction, Green Design, Green Packaging, Green Transportation, Recycling Capability.
	3	**Social Responsibility**	**C3**	Occupational Health and Safety, Corporate Social Responsibility, Labors' Benefits and Rights, Stakeholders' Rights, Employee Welfare, Child Labor Avoidance.
Smartness	4	**Manufacturing Technology Based Smart Tools**	**C4**	IoT, RFID, Sensors, 3D Printing, Robotics and Autonomous Systems, Artificial Intelligence, Machine Learning, Simulation, Augment Reality.
	5	**Business Management Based Smart Operations**	**C5**	ICS, CRM, MRP, ERP systems with Cloud Computing, Big Data, Block Chain, Cyber Security, Virtual Applications (virtual commerce, virtual remote support / maintenance, virtual education etc.) tools.

Table 4. Pairwise comparison matrix for criteria

	Criterion 1	Criterion 2	Criterion 3	Criterion 4	Criterion 5
Criterion1	Exactly Equal	Fairly Strong	Absolutely Strong	Slightly Strong	Fairly Strong
Criterion 2		Exactly Equal	Fairly Strong	1/ Slightly Strong	Exactly Equal
Criterion 3			Exactly Equal	1/ Very Strong	1/ Fairly Strong
Criterion 4				Exactly Equal	Slightly Strong
Criterion 5					Exactly Equal

Table 5. Pairwise comparison matrix for alternatives

with respect to C1	Supplier 1	Supplier 2	Supplier 3	Supplier 4	Supplier 5
Supplier 1	Exactly Equal	1/ Fairly Strong	Exactly Equal	1/ Slightly Strong	Fairly Strong
Supplier 2		Exactly Equal	Fairly Strong	Slightly Strong	Absolutely Strong
Supplier 3			Exactly Equal	1/ Slightly Strong	Fairly Strong
Supplier 4				Exactly Equal	Very Strong
Supplier 5					Exactly Equal
with respect to C2	**Supplier 1**	**Supplier 2**	**Supplier 3**	**Supplier 4**	**Supplier 5**
Supplier 1	Exactly Equal	Fairly Strong	Very Strong	Slightly Strong	Absolutely Strong
Supplier 2		Exactly Equal	Slightly Strong	1/ Slightly Strong	Fairly Strong
Supplier 3			Exactly Equal	1/ Fairly Strong	Slightly Strong
Supplier 4				Exactly Equal	Very Strong
Supplier 5					Exactly Equal
with respect to C3	**Supplier 1**	**Supplier 2**	**Supplier 3**	**Supplier 4**	**Supplier 5**
Supplier 1	Exactly Equal	1/ Slightly Strong	1/ Fairly Strong	1/ Fairly Strong	1/ Very Strong
Supplier 2		Exactly Equal	1/ Slightly Strong	1/ Slightly Strong	1/ Fairly Strong
Supplier 3			Exactly Equal	Exactly Equal	1/ Slightly Strong
Supplier 4				Exactly Equal	1/ Slightly Strong
Supplier 5					Exactly Equal
with respect to C4	**Supplier 1**	**Supplier 2**	**Supplier 3**	**Supplier 4**	**Supplier 5**
Supplier 1	Exactly Equal	Slightly Strong	1/ Fairly Strong	1/ Slightly Strong	Fairly Strong
Supplier 2		Exactly Equal	1/ Very Strong	1/ Fairly Strong	Slightly Strong
Supplier 3			Exactly Equal	Slightly Strong	Absolutely Strong
Supplier 4				Exactly Equal	Very Strong
Supplier 5					Exactly Equal
with respect to C5	**Supplier 1**	**Supplier 2**	**Supplier 3**	**Supplier 4**	**Supplier 5**
Supplier 1	Exactly Equal	1/ Fairly Strong	1/ Slightly Strong	1/ Very Strong	Slightly Strong
Supplier 2		Exactly Equal	Slightly Strong	1/ Slightly Strong	Very Strong
Supplier 3			Exactly Equal	1/ Fairly Strong	Fairly Strong
Supplier 4				Exactly Equal	Absolutely Strong
Supplier 5					Exactly Equal

The consistency ratios of the pairwise comparison matrices defuzzified using the DTraT method were calculated as 0.054, 0.053, 0.065, 0.058, 0.065, and 0.065 respectively. They are less than 0.1 so within limits. Therefore, the consistency of the judgment in all the comparison matrices is acceptable.

Based on Equation (10), geometric mean of each row of pairwise comparison matrices are calculated. For instance, the first row of Table 4 is calculated as given below;

$$\tilde{\tilde{r}}_1 = \sqrt[5]{\tilde{\tilde{a}}_{11} \otimes \tilde{\tilde{a}}_{12} \otimes \tilde{\tilde{a}}_{13} \otimes \tilde{\tilde{a}}_{14} \otimes \tilde{\tilde{a}}_{15}}$$

$$\tilde{\tilde{r}}_1 = \sqrt[5]{\begin{array}{c}(1,1,1,1;1,1)(1,1,1,1;1,1)\\ \otimes(3,4,6,7;1,1)(3.2,4.2,5.8,6.8;0.8,0.8)\\ \otimes(7,8,9,9;1,1)(7.2,8.2,8.8,9;0.8,0.8)\\ \otimes(1,2,4,5;1,1)(1.2,2.2,3.8,4.8;0.8,0.8)\\ \otimes(3,4,6,7;1,1)\ (3.2,4.2,5.8,6.8;0.8,0.8)\end{array}}$$

$\tilde{\tilde{r}}_1$=(2.29, 3.03, 4.19, 4.66;1,1)(2.45, 3.17, 4.08, 4.57;0.8,0.8)

Other $\tilde{\tilde{r}}_i$ values of the criteria are also calculated and Table 6 is obtained. After similar calculations are made for all alternatives, the priority weights of criteria and alternatives are determined by using Equation (12). For example, the priority weight of the first criterion could be calculated as follows;

$$\tilde{\tilde{w}}_1 = \tilde{\tilde{r}}_1 \otimes [\tilde{\tilde{r}}_1 \oplus \tilde{\tilde{r}}_2 \oplus \tilde{\tilde{r}}_3 \oplus \tilde{\tilde{r}}_4 \oplus \tilde{\tilde{r}}_5]^{-1}$$

$$\tilde{\tilde{w}}_1 = (2.29, 3.03, 4.19, 4.66;1,1)(2.45, 3.17, 4.08, 4.57;0.8,0.8)$$

$$\otimes \begin{bmatrix} (2.29, 3.03, 4.19, 4.66; 1,1)(2.45, 3.17, 4.08, 4.57; 0.8,0.8) \oplus (0.61, 0.70, 0.94, 1.18; 1, 1)(0.63, 0.71, 0.91, 1.12; 0.8, 0.8) \\ \oplus (0.19, 0.21, 0.27, 0.31; 1, 1)(0.19, 0.21, 0.26, 0.30; 0.8, 0.8) \oplus (1, 1.43, 2.30, 2.95; 1, 1)(1.09, 1.51, 2.19, 2.79; 0.8, 0.8) \\ \oplus (0.61, 0.70, 0.94, 1.18; 1, 1)(0.63, 0.71, 0.91, 1.12; 0.8, 0.8) \end{bmatrix}^{-1}$$

$$\tilde{\tilde{w}}_1 = (0.22, 0.35, 0.69, 0.99;1,1)\ (0.25, 0.38, 0.65, 0.91;0.8,0.8)$$

Table 6. Geometric means of pairwise comparison matrix for the criteria

	$\tilde{\tilde{r}}_i$
C1	(2.29, 3.03, 4.19, 4.66; 1, 1) (2.45, 3.17, 4.08, 4.57; 0.8, 0.8)
C2	(0.61, 0.70, 0.94, 1.18; 1, 1) (0.63, 0.71, 0.91,1.12; 0.8, 0.8)
C3	(0.19, 0.21, 0.27, 0.31; 1, 1) (0.19, 0.21, 0.26, 0.30; 0.8, 0.8)
C4	(1, 1.43, 2.30, 2.95; 1, 1) (1.09, 1.51, 2.19, 2.79; 0.8, 0.8)
C5	(0.61, 0.70, 0.94, 1.18; 1, 1) (0.63, 0.71, 0.91, 1.12; 0.8, 0.8)

Similar calculations were made for each criteria and alternatives, and the results given in Table 7 were obtained.

Global scores/weights of alternatives with respect to each criterion are calculated using Equation (14) and the results are represented in the subsection of Table 7. Overall scores/weights of each alternative are calculated summing up the fuzzy global scores of them and then this T-2 fuzzy scores are defuzzified using DTraT method and normalized as shown in the Table 8.

According to the results in Table 8, the order of the alternatives was obtained as S4, S2, S3, S1 and S5. Therefore, S4 is suggested as the best supplier among five of them, with respect to five criteria and decision maker preferences.

The company may ask the supplier 4 to maintain its sustainability in high performing areas and may encourage it to improve itself in areas considered to be incomplete.

Table 7. T-2 fuzzy priority weights of the criteria and T-2 fuzzy local (priority) and global weights of the alternatives

Criteria	C1	C2	C3	C4	C5
Criteria weights	(0.22, 0.35, 0.69, 0.99;1,1) (0.25, 0.38, 0.65, 0.91;0.8,0.8)	(0.06, 0.08, 0.16, 0.25;1,1) (0.06, 0.09, 0.14, 0.22;0.8,0.8)	(0.02, 0.02, 0.04, 0.07;1,1) (0.02, 0.03, 0.04, 0.06;0.8,0.8)	(0.10, 0.17, 0.38, 0.63;1,1) (0.11, 0.18, 0.35, 0.56;0.8,0.8)	(0.06, 0.08, 0.16, 0.25;1,1) (0.06, 0.09, 0.14, 0.22;0.8,0.8)
Alternatives	**Local weights**				
S1	(0.06, 0.08, 0.16, 0.25;1,1) (0.06, 0.09, 0.14, 0.22;0.8,0.8)	(0.22, 0.35, 0.69, 0.99;1,1) (0.25, 0.38, 0.65, 0.92;0.8,0.8)	(0.06, 0.08, 0.16, 0.25;1,1) (0.06, 0.09, 0.14, 0.22;0.8,0.8)	(0.10, 0.17, 0.38, 0.63;1,1) (0.11, 0.18, 0.35, 0.56;0.8,0.8)	(0.02, 0.02, 0.04, 0.07;1,1) (0.02, 0.03, 0.04, 0.06;0.8,0.8)
S2	(0.23, 0.36, 0.70, 1; 1,1) (0.26, 0.39, 0.65, 0.92;0.8,0.8)	(0.06, 0.09, 0.20, 0.33;1,1) (0.06, 0.10, 0.18, 0.29;0.8,0.8)	(0.03, 0.04, 0.10, 0.16;1,1) (0.03, 0.05, 0.09, 0.14;0.8,0.8)	(0.11, 0.18, 0.39, 0.64;1,1) (0.13, 0.20, 0.36, 0.57;0.8,0.8	(0.02, 0.02, 0.05, 0.08;1,1) (0.02, 0.03, 0.04, 0.07;0.8,0.8)
S3	(0.02, 0.03, 0.06, 0.11;1,1) (0.02, 0.03, 0.06, 0.10;0.8,0.8)	(0.04, 0.06, 0.14, 0.27;1,1) (0.04, 0.06, 0.12, 0.23;0.8,0.8)	(0.09, 0.14, 0.30, 0.50;1,1) (0.10, 0.15, 0.28, 0.44;0.8,0.8)	(0.09, 0.14, 0.30, 0.50;1,1) (0.10, 0.15, 0.28, 0.44;0.8,0.8)	(0.17, 0.30, 0.69, 1.07;1,1) (0.20, 0.33, 0.64, 0.97;0.8,0.8)
S4	(0.06, 0.09, 0.20, 0.33;1,1) (0.06, 0.10, 0.18, 0.29;0.8,0.8)	(0.03, 0.04, 0.10, 0.16;1,1) (0.03, 0.05, 0.09, 0.14;0.8,0.8)	(0.23, 0.36, 0.70, 1; 1,1) (0.26, 0.39, 0.65, 0.92;0.8,0.8)	(0.11, 0.18, 0.39, 0.64;1,1) (0.13, 0.20, 0.36, 0.57;0.8,0.8	(0.02, 0.02, 0.05, 0.08;1,1) (0.02, 0.03, 0.04, 0.07;0.8,0.8)
S5	(0.03, 0.04, 0.10, 0.16;1,1) (0.03, 0.05, 0.09, 0.14;0.8,0.8)	(0.11, 0.18, 0.39, 0.64;1,1) (0.13, 0.20, 0.36, 0.57;0.8,0.8)	(0.06, 0.09, 0.20, 0.33;1,1) (0.06, 0.10, 0.18, 0.29;0.8,0.8)	(0.23, 0.36, 0.70, 1; 1,1) (0.26, 0.39, 0.65, 0.92;0.8,0.8)	(0.02, 0.02, 0.05, 0.08;1,1) (0.02, 0.03, 0.04, 0.07;0.8,0.8)
	Global weights				
S1	(0.01, 0.03, 0.11, 0.25;1,1) (0.02, 0.03, 0.09, 0.21;0.8,0.8)	(0.01, 0.03, 0.11, 0.25;1,1) (0.02, 0.03, 0.09, 0.21;0.8,0.8)	(0.00, 0.00, 0.00, 0.01;1,1) (0.00, 0.00, 0.00, 0.01;0.8,0.8)	(0.01, 0.01, 0.07, 0.21;1,1) (0.01, 0.02, 0.06, 0.16;0.8,0.8)	(0.00, 0.00, 0.01, 0.04;1,1) (0.00, 0.00, 0.01, 0.03;0.8,0.8)
S2	(0.05, 0.12, 0.48, 0.99;1,1) (0.06, 0.14, 0.42, 0.84;0.8,0.8)	(0.00, 0.01, 0.03, 0.08;1,1) (0.00, 0.01, 0.03, 0.07;0.8,0.8)	(0.00, 0.00, 0.01, 0.02;1,1) (0.00, 0.00, 0.01, 0.01;0.8,0.8)	(0.00, 0.01, 0.04, 0.10;1,1) (0.00, 0.01, 0.03, 0.08;0.8,0.8)	(0.01, 0.01, 0.06, 0.16;1,1) (0.01, 0.02, 0.05, 0.13;0.8,0.8)
S3	(0.01, 0.03, 0.11, 0.25;1,1) (0.02, 0.03, 0.09, 0.21;0.8,0.8)	(0.00, 0.00, 0.01, 0.04;1,1) (0.00, 0.00, 0.01, 0.03;0.8,0.8)	(0.00, 0.00, 0.01, 0.03;1,1) (0.00, 0.00, 0.01, 0.03;0.8,0.8)	(0.02, 0.06, 0.26, 0.63;1,1) (0.03, 0.07, 0.23, 0.51;0.8,0.8)	(0.00, 0.01, 0.03, 0.08;1,1) (0.00, 0.01, 0.03, 0.07;0.8,0.8)
S4	(0.02, 0.06, 0.26, 0.62;1,1) (0.03, 0.07, 0.22, 0.51;0.8,0.8)	(0.01, 0.01, 0.06, 0.16;1,1) (0.01, 0.02, 0.05, 0.13;0.8,0.8)	(0.00, 0.00, 0.01, 0.03;1,1) (0.00, 0.00, 0.01, 0.03;0.8,0.8)	(0.01, 0.03, 0.15, 0.40;1,1) (0.01, 0.04, 0.13, 0.32;0.8,0.8)	(0.01, 0.03, 0.11, 0.25;1,1) (0.02, 0.03, 0.09, 0.21;0.8,0.8)
S5	(0.00, 0.01, 0.03, 0.07;1,1) (0.00, 0.01, 0.03, 0.06;0.8,0.8)	(0.00, 0.00, 0.01, 0.02;1,1) (0.00, 0.00, 0.01, 0.02;0.8,0.8)	(0.00, 0.01, 0.03, 0.07;1,1) (0.00, 0.01, 0.03, 0.06;0.8,0.8)	(0.00, 0.00, 0.02, 0.05;1,1) (0.00, 0.00, 0.02, 0.04;0.8,0.8)	(0.00, 0.00, 0.01, 0.02;1,1) (0.00, 0.00, 0.01, 0.02;0.8,0.8)

Table 8. T-2 fuzzy overall, defuzzified and crisp weights of the alternatives

	T-2 fuzzy overall weights	Defuzzified weights	Normalized crisp weights	Rank
S1	(0.03, 0.08, 0.31, 0.76; 1,1) (0.04, 0.09, 0.26, 0.61; 0.8,0.8)	0.264	0.155	4
S2	(0.06, 0.15, 0.61, 1.35; 1,1) (0.08, 0.18, 0.53, 1.13; 0.8,0.8)	0.494	0.289	2
S3	(0.04, 0.10, 0.43, 1.04; 1,1) (0.05, 0.12, 0.37, 0.84; 0.8,0.8)	0.362	0.212	3
S4	(0.05, 0.14, 0.59, 1.48; 1,1) (0.07, 0.16, 0.51, 1.19; 0.8,0.8)	0.506	0.297	1
S5	(0.01, 0.02, 0.09, 0.23; 1,1) (0.01, 0.03, 0.08, 0.19; 0.8,0.8)	0.080	0.047	5

4. SCENARIO ANALYSIS AND DISCUSSIONS

In this section, a scenario analysis has been made to analyze the effect of different conditions on the rankings of suppliers, with the results obtained by the IT-2 FAHP method proposed for smart and sustainable supplier selection. 22 scenarios related to different criteria and weights have been investigated. Table 9 shows the details of the scenarios considered. Especially, it was emphasized that obtaining information about the importance of smart and sustainable evaluation criteria and what kind of a change will be in the supplier ranking in case of choosing these criteria individually and together.

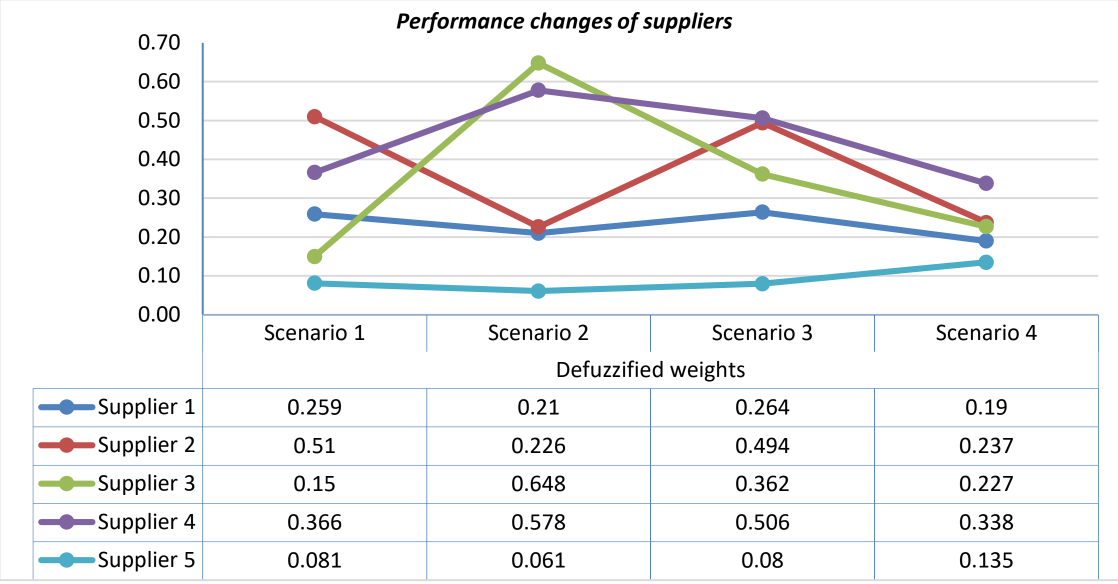
In the first stage, a general analysis is made for the first four scenarios. In line with the inferences obtained from this, in the second stage, 18 more scenarios, nine for sustainability and nine for smartness, are created and the results are analyzed in order to see more clearly the effect of changes in the weights of sustainable and smartness criteria on the ranking of current case. The first scenario shows the evaluation made by taking into account only the sustainability criteria, while the scenario 2 shows the evaluation made only by considering the smart criteria in the current case. The scenario 3 indicates the current global weights for all criteria and then, all criteria are considered to have the equal importance weight in the scenario 4 in order to analyze the effects of smart and sustainable criteria together on supplier selection. For the second stage, based on the current case only sustainability criteria weights are increased by between 90% and 10% respectively in scenario 5 -13, and then, only smartness criteria weights are increased by between 10% and 90% respectively in scenario 14 -22.

For Scenario 1, S2 took the highest rank and, S4 takes the second rank among to all the suppliers. For Scenario 2, S3 took the highest rank and, S4 takes the second rank again, among to all the suppliers. Analysis results for scenario 3 and 4 has the same order as S4, S2, S3, S1, S5. It is observed that different rankings of the suppliers are obtained for the first two scenarios. This shows that there is distinctive effect of smart and sustainability dimensions rather than changes in the weights on selecting appropriate supplier type.

Considering the results of scenario analysis, S5 has the worst performance in all cases, while S1 ranked 4th in all scenarios except the first case. In line with these results, the decision maker can eliminate the S5 and S1 suppliers and make the most appropriate selection among the other three suppliers that show the best performance in different scenarios according to their priorities on the basis of criteria. Accordingly, it would be appropriate for the decision maker to work with S2 if aiming sustainability, to work with S3 if aiming smartness, and to work with S4 if takes into account both and aiming them simultaneously.

Table 9. Results of scenario analysis

Number of Scenarios	**Decision criteria**		**Ranking order of suppliers**
1	C1, C2 and C3 (Sustainability criteria only)		S2- S4- S1- S3- S5
2	C4 and C5 (Smartness criteria only)		S3- S4- S2- S1- S5
3	C1, C2, C3, C4 and C5 (Current case)		S4- S2- S3- S1- S5
4	C1, C2, C3, C4 and C5 (All have equal weights)		S4- S2- S3- S1- S5
5	**C1, C2, C3, C4 and C5 (Sustainability criteria weights increase by**	90%)	S2- S4- S3- S1- S5
6		80%)	S2- S4- S3- S1- S5
7		70%)	S2- S4- S3- S1- S5
8		60%)	S2- S4- S3- S1- S5
9		50%)	S2- S4- S3- S1- S5
10		40%)	S2- S4- S3- S1- S5
11		30%)	S2- S4- S3- S1- S5
12		20%)	S2- S4- S3- S1- S5
13		10%)	S4- S2- S3- S1- S5
14	**C1, C2, C3, C4 and C5 (Smartness criteria weights increase by**	10%)	S4- S2- S3- S1- S5
15		20%)	S4- S2- S3- S1- S5
16		30%)	S4- S2- S3- S1- S5
17		40%)	S4- S2- S3- S1- S5
18		50%)	S4- S2- S3- S1- S5
19		60%)	S4- S2- S3- S1- S5
20		70%)	S4- S2- S3- S1- S5
21		80%)	S4- S2- S3- S1- S5
22		90%)	S4- S3- S2- S1- S5

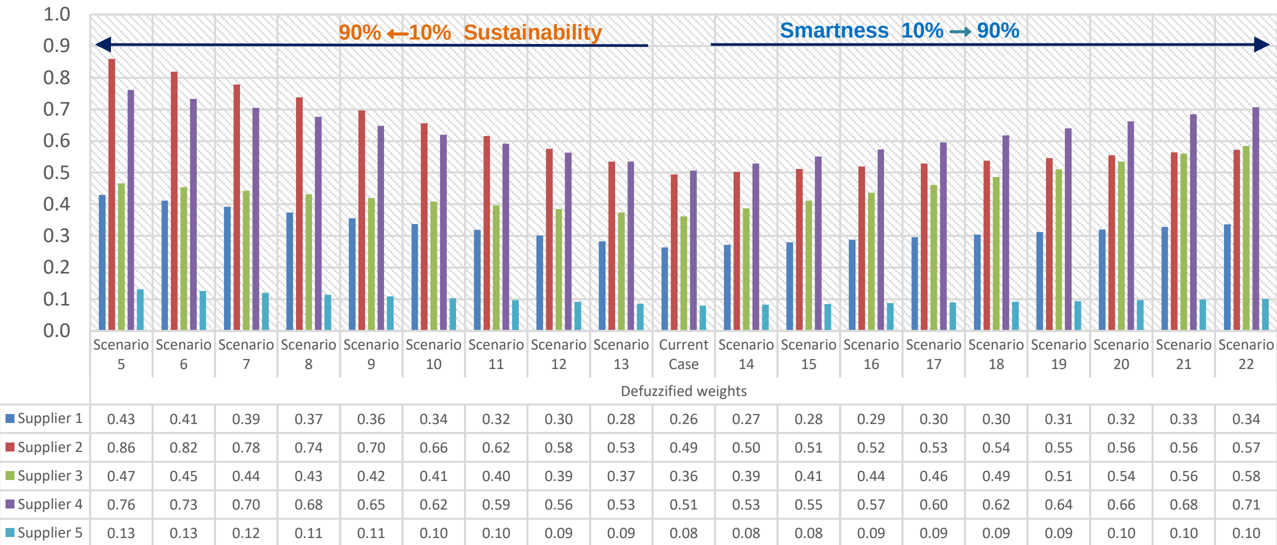


	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Supplier 1	0.259	0.21	0.264	0.19
Supplier 2	0.51	0.226	0.494	0.237
Supplier 3	0.15	0.648	0.362	0.227
Supplier 4	0.366	0.578	0.506	0.338
Supplier 5	0.081	0.061	0.08	0.135

Figure 3. Performance changes of suppliers in result of scenario analysis for first stage

Figure 3 shows the comparison and change in the defuzzified weights of the suppliers obtained as a result of the scenarios for first stage. Hereby, it is observed that S5 and S1 generally have close weight values and stable ranks in all scenarios, while S2, S3, S4 have different weight values in each scenario and therefore different ranks on the suppliers' ranking.

In the second stage scenario analysis, the transitions between scenario 1, current case and scenario 2 are shown in more detail. According to Figure 4, which shows the weight values of suppliers in the second stage scenario analysis, for Scenarios 5-12, S2 took the highest rank and, S4 takes the second rank again as in scenario 1 and the remaining order is the same as the current case. For analysis results for scenarios 13-20 have the same order as in the current case. and finally, for scenario 22, S2 took the highest rank again, but S4 and S3 have changed places in the current case ranking.



	Scenario 5	Scenario 6	Scenario 7	Scenario 8	Scenario 9	Scenario 10	Scenario 11	Scenario 12	Scenario 13	Current Case	Scenario 14	Scenario 15	Scenario 16	Scenario 17	Scenario 18	Scenario 19	Scenario 20	Scenario 21	Scenario 22
Supplier 1	0.43	0.41	0.39	0.37	0.36	0.34	0.32	0.30	0.28	0.26	0.27	0.28	0.29	0.30	0.30	0.31	0.32	0.33	0.34
Supplier 2	0.86	0.82	0.78	0.74	0.70	0.66	0.62	0.58	0.53	0.49	0.50	0.51	0.52	0.53	0.54	0.55	0.56	0.56	0.57
Supplier 3	0.47	0.45	0.44	0.43	0.42	0.41	0.40	0.39	0.37	0.36	0.39	0.41	0.44	0.46	0.49	0.51	0.54	0.56	0.58
Supplier 4	0.76	0.73	0.70	0.68	0.65	0.62	0.59	0.56	0.53	0.51	0.53	0.55	0.57	0.60	0.62	0.64	0.66	0.68	0.71
Supplier 5	0.13	0.13	0.12	0.11	0.11	0.10	0.10	0.09	0.09	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.10	0.10	0.10

Figure 4. Weight values of suppliers in result of scenario analysis for second stage

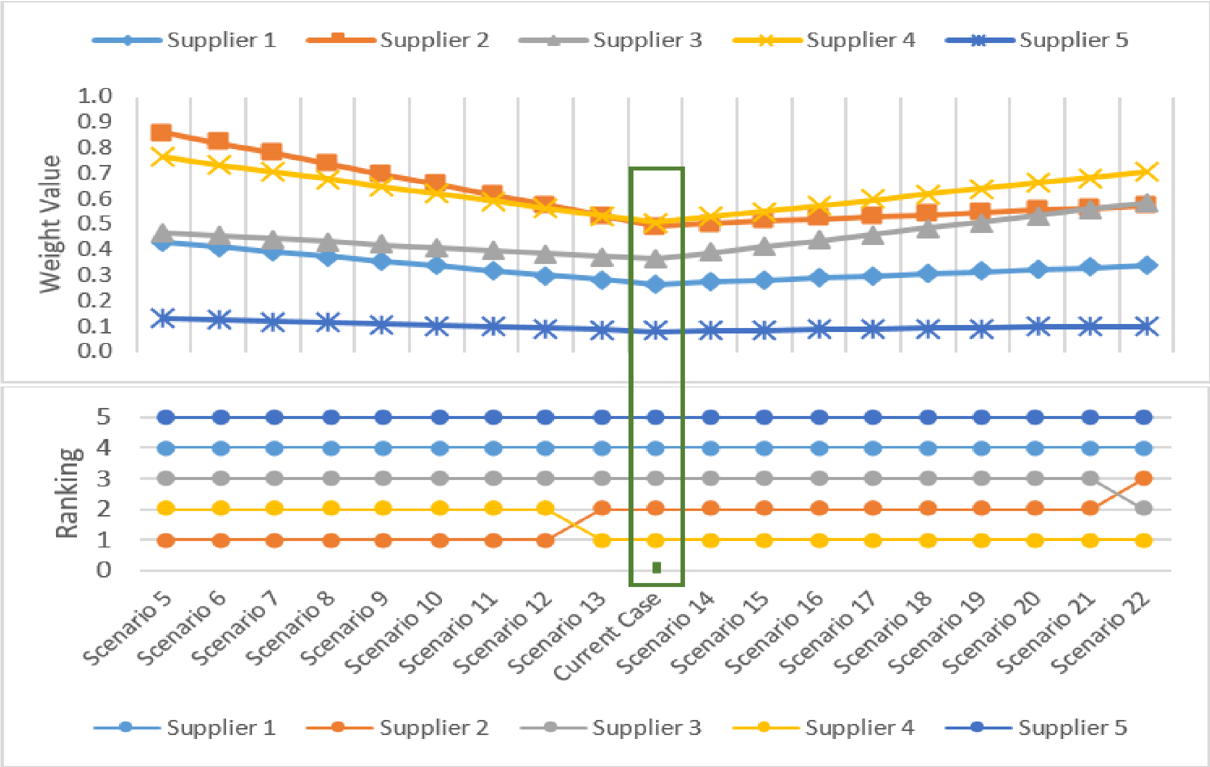


Figure 5. Ranking of suppliers in result of scenario analysis for second stage

Figure 5 shows the comparison in the weight values and ranking of the suppliers obtained as a result of the scenarios for second stage. As it is seen in the figure, there aren't much differences between the weight values of the suppliers and this has not made a significant change in their rankings. that is, in some scenarios only the rank of the two suppliers has changed according to the current case. Based on this, it is concluded that the inferences reached through the scenario analysis results in the first stage are consistent.

Again, as could be seen in Figure 6, the changes made on the weights of the sustainability and smartness criteria on the current case increased the performance of the suppliers linearly, but did not affect the ranking very much. On the contrary, changes made on the criteria themselves changed the performance of suppliers more sharply and have been more effective and distinctive on the supplier ranking.

According to the scenario analysis results, this research proved that the proposed approach could produce satisfactory results and provide appropriate information to guide managers in decision making problems.

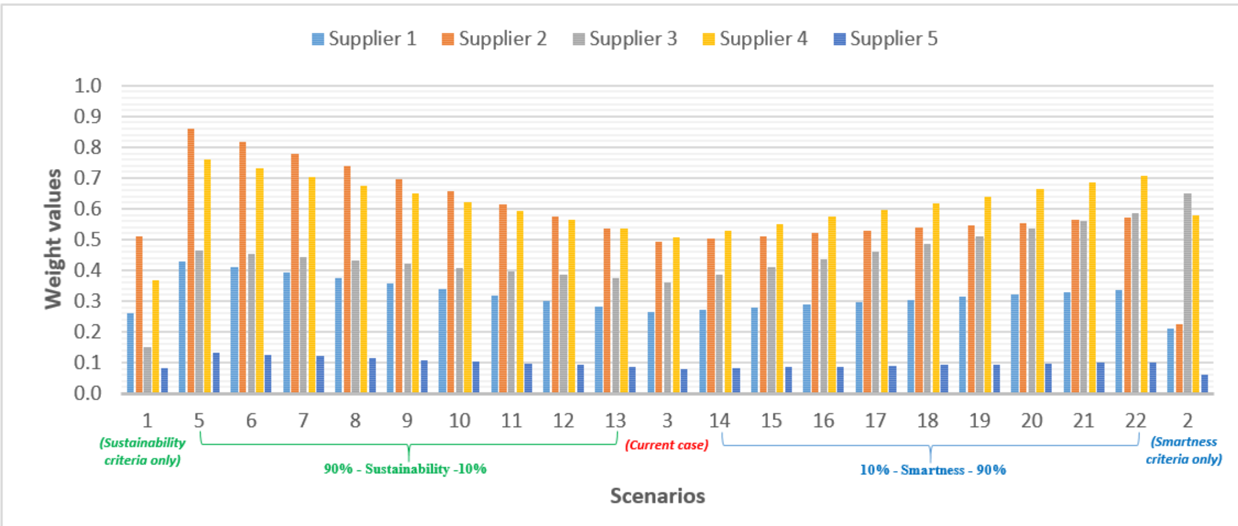


Figure 6. Performance changes of suppliers for all scenarios

5. CONCLUSION

The importance of working with the right suppliers in a more and more competitive environment is incontestable, as suppliers have an enormous impact on the organizations performance and their supply chains. therefore, supplier selection problem has attracted high attention in current literature.

Despite the prevalence of sustainable supplier selection recently, research based on the Fuzzy MCDM approaches in Industry 4.0 era, which includes technologies capable of rapid data collection, analysis and modification supporting supply chain management, is in its infancy yet. Because, for the selection of supplier in the logistics 4.0 environment, accessive issues regarded to the features of logistics 4.0 must be taken into consideration [29].

The current research identified five effective basis criteria on both smart and sustainable (environmental, economic and social) aspects for supplier selection process and applied IT-2 FAHP method to evaluate the overall performance of suppliers. We applied trapezoidal IT-2 FS to reduce the uncertainty level and obtain more realistic results. Hence, we successfully applied IT-2 FAHP model and obtained more reliable results for smart and sustainable supplier selection decision of automotive industry in this study.

As future studies, more academic research is needed to attract practitioners' attention on smart and sustainable supply chain management. It is recommended considering many different evaluation criteria and sub-criteria for the further research. In order to get criteria weights, other multi-criteria decision making methods under IT-2 FS could be used or existing ranking methods can be used together with AHP or different fuzzy extension of AHP can be taken into account to solve problem and compared in terms of suitability. Moreover, the methodology could be applied to the smart and sustainable supplier selection of companies in other industries and a different structure could be formed by integrated with other methods and mathematical models.

DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

AUTHORS' CONTRIBUTIONS

Belkız TORĞUL: Performed the design and implementation, analyzed the results, and wrote the manuscript.

Turan PAKSOY: Performed the design and verified the results by checking.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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