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Research Article

A Fuzzy Best Worst approach to the determination of the importance level of digital supply chain on sustainability

Dijital tedarik zincirinin sürdürülebilirlik üzerindeki önem düzeyinin belirlenmesine yönelik Bulanık Best Worst yaklaşımı

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Abstract

In today's world where the importance of digitalization is increasing day by day, companies to increase their competitiveness have focused on digital supply chain instead of traditional supply chain. In a world where resources are constantly decreasing, the concept of sustainability has become very crucial in every part of life. Digital technologies, on the other hand, have a direct relationship with sustainability. Sustainability has three main dimensions: economic, environmental, and social. Therefore, the aim of this study is to evaluate digital supply chain on 3 basic dimensions of sustainability. For this purpose, Fuzzy Best Worst Method (F-BWM) was used to define the importance level of criteria. Findings reveal that the concept of sustainability in textile firms in Turkey is generally perceived within an economic and environmental area, rather than within a social dimension. This study is very important in putting forward digital technologies which utilizing in supply chain and the impact of the digital supply chain on sustainability.

Keywords: Fuzzy BWM, Textile Industry, Sustainability, Digital Supply Chain

Jel Codes: C44, L67, M10, Q56

Öz

Dijitalleşmenin öneminin her geçen gün arttığı günümüz dünyasında şirketler rekabet güçlerini artırmak için geleneksel tedarik zinciri yerine dijital tedarik zincirine odaklanmaktadır. Kaynakların sürekli azaldığı bir dünyada ise sürdürülebilirlik kavramı hayatın her alanında çok önemli hale gelmektedir. Diğer yandan dijital teknolojilerin ise sürdürülebilirlik ile doğrudan bir ilişkisi vardır. Sürdürülebilirlik üç temel boyuta (ekonomik, çevresel, sosyal) sahiptir. Bu nedenle bu çalışmanın amacı, dijital tedarik zincirini sürdürülebilirliğin 3 temel boyutu üzerinde değerlendirmektir. Bu amaçla, kriterlerin önem düzeyini belirlemek için Bulanık Best Worst Yöntemi (F-BWM) kullanılmıştır. Sonuçlar, Türkiye'deki tekstil işletmelerinde sürdürülebilirlik kavramının genellikle sosyal boyuttan ziyade ekonomik ve çevresel bir alanda algılandığını ortaya koymaktadır. Bu çalışma, tedarik zincirinde kullanılan dijital teknolojileri ve dijital tedarik zincirinin sürdürülebilirliğe etkisini ortaya koyması açısından oldukça önemlidir.

Anahtar Kelimeler: Bulanık BWM, Tekstil Endüstrisi, Sürdürülebilirlik, Dijital Tedarik Zinciri

JEL Kodları: C44, L67, M10, Q56

Introduction

Supply Chain Management (SCM) is an integration of the business process that provides products, services, and information that add value to customers via suppliers (Cooper, Lambert and Pagh, 1997: 2). It has become a globally accepted understanding that SCM is an inseparable part of organizations and has an important place in company success and customer satisfaction. SCM is a very crucial part of all organizations. An SCM manager/expert always desires to get cheaper, faster, and better. Meanwhile, supply chains face uncertainty, complex and cost risks in an environment with today's consumers whose demands and needs are constantly changing (Wu, Yue, Jin, and Yen, 2016: 1). Industry 4.0 transforms supply chain into an intelligent production system based on cyber-physical interactions of connected elements and it emphasizes that production is based on digital technology (Yıldız, 2018a: 547). Nowadays many industries especially the manufacturing industry have become digital. As a result, they have reached an automated, efficient, and agile structure. The supply chain, which is a vital part of manufacturing, is highly affected by this new digital age. With the digital technologies used in traditional supply chains, all activities in the chain can be more understood, explained, and predicted by participants. Digital supply chain has some distinctive features. For instance, it provides speed, flexibility, global connectivity, real-time inventory (Büyüközkan and Göçer 2018: 165- 166). Thanks to digital supply chain applications, myriad information can be collected, business processes can be improved, and gain higher efficiency and quicker response (Wu et al., 2016: 4).

According to WCED (1987), the meaning of sustainability is to meet the goods and services demanded by customers by protecting the resources needed by future generations. Carter and Easton (2011) addressed that the concept of sustainability is a hot topic both among companies trying to survive and societies with high environmental awareness. Moreover, the importance of sustainability is increasing as days pass because our resources are limited and sustainability has become a buzzword among stakeholders (Arslan, 2020: 233). Stević, Pamučar, Puška, and Chatterjee (2020) have highlighted that organizations all over the world try to minimize their negative effects on the environment with sustainable supply chain practices. Previous studies reveal that the topic of sustainability and supply chain management has attracted a great deal of attention from both the industry and researchers (Seuring, Sarkis, Müller and Rao, 2008; Kusi-Sarpong, Gupta and Sarkis, 2019; Arslan, 2020; Karmaker, Ahmed, Ahmed, Ali, Moktadir and Kabir, 2021). It has become an accepted understanding to examine sustainability in 3 basic dimensions (economic, environmental, and social). Relationships between these three dimensions are necessary for a better understanding of sustainability. Seuring et al. (2008) emphasize that economic, environmental, and social subjects should be considered along all supply chains. According to Carter and Rogers (2008), companies have gained vital advantages considering the interests of the environment and society in the activities in all supply chain. Wilding, Wagner, Gimenez and Tachizawa (2012) addressed those previous studies attach importance to environmental sustainability but there are a limited number of studies on social sustainability.

Some studies (Dubey, Gunasekaran, Childe, Wamba and Papadopoulos, 2016; Bag, Telukdarie, Pretorius and Gupta, 2018; Yıldız, 2018b; Melo, Macedo, Baptista, 2019) have revealed that digital technologies can improve supply chain sustainability. However, most of the previous research has only revealed sustainable SCM practices for traditional supply chains, while do not give importance to reveal the effects of emerging digital technologies on sustainability. Therefore, it can be said that this area is under-researched. For this reason, this study has been planned. The main purpose of this study is to evaluate the impact of leveraging digital supply chain on sustainability using the Fuzzy BWM (F-BWM) which is one of the current MCDM methods. Akandere and Paksoy (2020) state that digital technologies have a direct relationship with economic, environmental, and social issues and these three dimensions increase the quality of sustainability. In this context, it is thought that digital technologies used on the supply chain have a significant impact on three dimensions of sustainability. For this reason, this study has been planned to evaluate the impact of digital supply chain on 3 basic dimensions (economic, environmental, and social) of sustainability. The textile sector can be defined as a branch of industry related to the design, production, and distribution of yarn, cloth, and clothing. As stated in Özek and Yıldız (2020), this sector has started to use various digital technologies in the supply chain process. There is a limited sector that uses digital technologies in supply chain process in Turkey, that's why the case study in this paper is associated with the Textile Firms in Turkey.

MCDM, as defined by Xu and Yang (2001), is decision-making in the presence of multiple criteria that generally conflict with each other. MCDM can be generally examined under two headings; first is to obtain decision information, including criterion weights and criterion values, second is to gather the information in a specific approach, and then ranking the alternatives (Triantaphyllou, 2000: 5-6). The BWM has been proposed by Rezaei (2015), is a method to determine the weights of criteria. Unlike many other MCDM's, BWM uses reference comparisons. This means that determining the preference of the best criterion over all the other criteria and the preference of all the criteria over the worst criterion by using a number (1-9) (Rezaei, 2015: 50-51). Bellman and Zadeh (1970) addressed that much of the decision-making process takes place in an environment of complexity and uncertainty. The fuzzy sets were introduced by Zadeh (1965) are used with many MCDM techniques in the literature. Because using fuzzy information to reflect decision information more accurately in some MCDM issues may be more effective. BWM's reference comparisons can be performed using fuzzy numbers on some subjects and more accurate results can be obtained. In this study, a fuzzy-based BWM using fuzzy comparison judgments was used to define the weights of criteria.

In recent years, some authors (Büyüközkan and Göçer, 2018; Cole, Stevenson and Aitken, 2019; Özek and Yıldız 2020; De Vass, Shee and Miah, 2020; Nasiri, Ukko, Saunila and Rantala, 2020) have studied on digital supply chain. In addition to this, in some previous studies (Ecer and Pamucar 2020; Amiri, Hashemi-Tabatabaei, Ghahremanloo, Keshavarz-Ghorabaee, Zavadskas and Banaitis, 2020; Hoseini, Fallahpour, Wong, Mahdiyar, Saberi and Durdyev, 2021), F-BWM has been applied to determine criterion weights within the framework of the concept of sustainability. However, F-BWM method has not been applied yet in evaluating the impact of leveraging digital supply chain on sustainability. Accordingly, this study will contribute to practitioners and researchers. This study is organized as follows. Firstly, a literature review is presented. Then, F-BWM is introduced step by step, and the case study is presented. Finally, conclusion and recommendation are given.

Literature review

Digital supply chain (DSC)

Digital platforms, which are developing day by day, gain importance in the business world and provide supply chain management to change and evolve (Yıldız, 2018b: 1218). DSC, as defined by Büyüközkan and Göçer (2018), is a concept related to using and managing innovative technologies such as mobile robots, drones, Internet of Things (IoT), big data analytics (BDA), Virtual Reality (VR), Augmented Reality (AR) and Artificial Intelligence (AI), sensors, etc. in supply chain processes. The adoption of digital technologies in supply chain management has vital in the business environment. Nowadays, firms have focused on utilizing digital technologies, such as IoT, BDA, AR/VR, and AI in their SCM process. Chen, Ming, Zhou, and Chang (2020) emphasize that these digital technologies ensure all processes in a supply chain to be perceptible, diagnosable, interpretable, predictable, controllable. Yang, Fu and Zhang (2021) state that in the last decade, digital technologies have been studied extensively by practitioners and researchers but there is limited information on the adoption of digital technologies at the supply chain level.

Digital technologies are quite extensive-term and they comprise entire technologies which have digital elements. That's why, the most commonly used digital technologies in the context of SCM: IoT, BDA, AR/VR, and AI are explained in this study. IoT is a structure that enables things to communicate with each other (Yıldız, 2018a: 550). IoT generally is used to track the production process in logistics and warehouse operations. BDA systematically takes information from data sets that are too large or complex generated from various sources and analyses it. BDA can help optimize the energy utilization efficiency of heavy production infrastructures and predict, monitor and control product quality (Chen et al., 2020: 5). AI is the simulation of things that require human intelligence processes by machines. AI is mainly used to classify, analyse, and draw predictions from data. AI can be used to reduce unplanned stoppages and product defects hence it ensures efficient production plans. According to Yıldız (2018a), Industry 4.0 ensures things to communicate with each other and with people by monitoring physical processes with cyber-physical systems in modular smart factories. IoT and AI are generally associated with Industry 4.0 while BDA is dependent on them because obtained data from IoT devices need to be analysed with data analytic methods so that be useful (Yang et al., 2021: 2). AR refers to "a form of virtual reality where the participant's head-mounted display is transparent, allowing a clear view of the real world" (Wu, Lee, Chang, and Liang, 2013: 42). Employees can view and quickly learn solutions to complex technical problems during production and maintenance using AR. VR that also called computer-simulated reality can be defined as a computer-generated experience that combines the real and the imaginary (Shin, 2018: 65). Nowadays, employees are trained with VR tools because VR offers unlimited space to employees by accurately simulating firm's operations.

In the broad sense, firms can improve their supply chain performance via digital technologies. Some previous studies (Brandon-Jones, Squire, Autry, and Petersen, 2014; Gunasekaran, Papadopoulos, Dubey, Wamba, Childe, Hazen, and Akter, 2017; Govindan, Cheng, Mishra, and Shukla, 2018; Özek and Yıldız, 2020; Attaran, 2020; Saryatmo and Sukhotu, 2021) have shown that firms with digital technologies mentioned above improve their supply chains performance such as flexibility, higher uptime, lower warehousing and inventory costs, lower supply chain risk, and more efficient delivery.

Sustainability

Sustainability is one of the contemporary themes of today's world whose resources are decreasing day by day and is one of the main problems that managers focus on. Elkington (1998) addressed that there are three key factors of sustainability (environmental, economic and, social). Economic sustainability increases the level of welfare while increasing the consumption of goods and services, environmental sustainability makes it necessary to be aware of resources, especially non-renewable energy resources, and to act by taking them into account in our activities and social sustainability aims to improve the health, quality of life, and education of employees.

In the last decade, there are many studies in which MCDM methods are used within the scope of sustainable SCM. Çifçi and Büyüközkan (2011) applied the Fuzzy Analytic Hierarchy Process (F-AHP) to evaluate and select green suppliers. According to the result from the study, environmental performance and product price is the most important main and sub-criterion respectively. A similar study was handled by Wang Chen, Chou, Luu, and Yu (2016), in which they used fuzzy AHP and TOPSIS methods. Accordingly, the most important criterion is product price. Uçal Sarı, Çayır Ervural, and Bozat (2017) discussed the supplier evaluation criteria with the DEMATEL technique in sustainable SCM. Findings show that delivering on time is the most important criterion while pollution control is the least important criterion. Awasthi, Govindan, and Gold (2018) handled the sustainable supplier selection problem using Fuzzy AHP and Fuzzy VIKOR. The study has revealed that economic and cost are the most important main and sub-criterion respectively. For the same purpose, Ecemiş and Yaykaşlı (2018) used AHP and Gray Relational Analysis methods. Different from previous studies, in this study, two main criteria: organizational and strategic performance were handled. Findings indicate that organizational performance main criterion is more important than strategic performance main criterion. The quality sub-criteria examined under the strategic performance main criterion is the sub-criterion with the highest level of importance. Chen et al. (2020) used the hybrid rough-fuzzy DEMATEL-TOPSIS methods to sustainable supplier selection. Cost reduction has been found the most important criterion. Ecer (2021) solved the same problem using FUCOM and MAIRCA methods. The results obtained from the study show that the most important sustainability dimension is the economic dimension, followed by the environmental and social dimensions, respectively. Moreover, the most important sub-criterion is informing, and the least important sub-criterion is flexibility. When the literature is examined, it is seen that a limited number of studies address the impact of digital supply chain on sustainability. On the other hand, innovative information technologies, when combined with Industry 4.0 initiatives, ensure a sustainable culture in supply chains (Yıldız, 2018b: 1217). In this context, it can be said that digital technologies using in SCM have an essential role to improve three dimensions of sustainability. For example, in the economic dimension sense; using the IoT and BDA ensure to improve the supply flexibility and reduction logistic costs. In the environmental dimension sense, using various digital technologies, energy consumption can be controlled, and customers can purchase environmentally friendly products. In the social dimension sense, VR/AR ensure not only increase working efficiency but also healthy and safe working places (Chen et al., 2020: 2). In this study, the impact of digital supply chain on three dimensions of sustainability is evaluated. Table 1 shows the sources and explanations for the criteria used in the paper.

Table 1: Evaluation Criteria

Criteria	Sub-criteria	Author	Brief Explanation
Economic (EC)	EC_1: Supply flexibility	Büyüközkan and Göçer (2018), Giannakis, Spanaki, and Dubey (2019)	Digital technologies that dynamically restructure supply chain processes according to changing requirements can boost supply chain flexibility.
	EC_2: Product quality	Abdel-Basset, Manogaran, and Mohamed (2018), Chen et al. (2020)	Digital technologies help firms improve product quality by providing perfect information about the product.
	EC_3: Cost reduction	Raman, Patwa, Niranjan, Ranjan, Moorthy, and Mehta (2018), Büyüközkan and Göçer (2018)	Digital technologies reduce costs on the supply chain in different ways. For instance, BDA prevent product defects, surplus stocks and determine root causes of failures.
	EC_4: Delivery of product	Büyüközkan and Göçer (2018), Luthra, Govindan, Kannan, Mangla, and Garg (2017)	Firms can improve the product delivery process with digital technologies that ensure the right delivery and service of the product.
Environmental (EN)	EN1: Green manufacturing	Bag et al. (2018), Chen et al. (2020)	BDA and machine learning help increasing production efficiency and controlling energy consumption, and emissions.
	EN2: Green - eco design	Diabat, Kannan, and Mathiyazhagan (2014), Büyüközkan and Göçer (2018)	Using digital technology to reduce energy consumption, recycle components of materials, and prevent or reduce the use of hazardous products.
	EN3: Green purchasing	Jaiswal and Kant (2018)	With the help of digital technologies, customers purchase environmentally friendly, recyclable, and sustainable products.
	EN4: Green logistics	Anitha and Patil (2018)	Digital technologies make possible green logistics. For instance, autonomous logistics, product intelligence, intelligent transport systems, physical internet, intelligent cargo, self-organizing logistics, etc.
Social (SO)	SO1: Voice of the customer	Griffin and Hauser (1993), Mahdiraji, Hafeez, Kord, and Kamardi (2020)	Requirements, demands, perceptions, and preferences of customers, reach firms with digital technologies easily and quickly.
	SO2: Health and safety working environment	Ajayi, Oyedele, Delgado, Akanbi, Bilal, Akinade, and Olawale (2019)	It is the use of digital technologies to minimize and control the factors threatening health and safety in working places.
	SO3: The rights of stakeholders	Kuo, Wang, and Tien (2010), Chen et al. (2020)	To ensure and protect interests and rights of shareholders, consumers, communities by using digital technologies.
	SO4: Employee's development	Bag et al. (2018), Frank, Dalenogare, and Ayala (2019)	There are many positive effects of digital technologies on employee's development and efficiency.

Methodology

General information on fuzzy set

Fuzzy set theory was proposed by Zadeh (1965) for a true reflection of the human assessment in the decision-making process. Fuzzy sets can solve problems better under uncertainty in other words under uncertain environments. When we consider many decision-making problems, they consist of various components (e.g., goals, constraints, etc.) that could not be known exactly. The problems we face in real life are often unclear and imprecise. Therefore, sometimes decision-makers should make decisions using non-numerical information. In such cases, fuzzy sets are included in the decision-making phases and more effective decisions can be obtained (Organ and Kenger, 2012: 121) and fuzzy sets have been used in many decision-making problems (Moslem, Gul, Farooq, Celik, Ghorbanzadeh, and Blaschke, 2020: 5). Fuzzy numbers are a subset of fuzzy sets and linguistic variables need to be defined with fuzzy numbers. Triangular fuzzy numbers (TFNs) were used in this study. The membership function of a TFN denoted as $\tilde{A} = (l, m, u)$, where $l \leq m \leq u$, can be defined as in Eq. (1) (Ecer, 2015: 6).

$$\mu_{\tilde{A}}(x) = \begin{cases} 0, & x < l \\ \frac{(x-l)}{(m-l)}, & l \leq x < m \\ \frac{(u-x)}{(u-m)}, & m \leq x \leq u \\ 0, & x > u \end{cases} \quad (1)$$

Let two triangular fuzzy numbers $\tilde{A}_1 = (l_1, m_1, u_1)$ and $\tilde{A}_2 = (l_2, m_2, u_2)$ where $l_1 \leq m_1 \leq u_1$ *and* $l_2 \leq m_2 \leq u_2$, mathematical operations of the two TFNs are calculated as follows (Ertuğrul and Karakaşoğlu, 2009: 705) :

Fuzzy addition operation is described as in Eq. (2):

$$\tilde{A}_1 \oplus \tilde{A}_2 = (l_1 + l_2,\ m_1 + m_2,\ u_1 + u_2) \quad (2)$$

Fuzzy subtraction operation is described as in Eq. (3):

$$\tilde{A}_1 \ominus \tilde{A}_2 = = (l_1 - u_2,\ m_1 - m_2,\ u_1 - l_2) \quad (3)$$

Fuzzy multiplication operation is described as in Eq. (4):

$$\tilde{A}_1 \otimes \tilde{A}_2 = = (l_1 . l_2,\ m_1 . m_2,\ u_1 . u_2) \quad (4)$$

Fuzzy division operation is described as in Eq. (5):

$$\tilde{A}_1 \oslash \tilde{A}_2 = = (l_1 / u_2,\ m_1 / m_2,\ u_1 / l_2) \quad (5)$$

Fuzzy inverse operation is described as in Eq. (6):

$$\tilde{A}_1^{-1} = (1/u_1,\ 1/m_1,\ 1/l_1) \quad (6)$$

Fuzzy Best Worst method (F-BWM)

The Best Worst Method (BWM) was developed by Rezaei (2015). This method using for determining the weights of criteria. There are some studies using the BWM and F-BWM methods in the literature. Ecer and Pamucar (2020) selected a sustainable supplier using F-BWM and COCOSO'B techniques. Torkayesh, Iranizad, Torkayesh and Basit (2020) used BWM and WASPAS methods for digital supplier selection. Khan, Haleem, and Khan (2021), identified and prioritized risk dimensions for managing a Halal supply chain using F-BWM.

In this method, the best and worst criteria are determined by the experts / decision-makers (DMs) and the rest of the criteria are compared with them in pairwise comparisons (Best-to-Others and Others-to-Worst) (Çakır and Can, 2019: 9). With this method, the consistency of the comparisons made by DMs can be calculated (Guo and Zhao 2017: 24-26). Different approaches of BWM e.g., linear (Rezaei, 2016), Fuzzy (Guo and Zhao, 2017), Euclidean (Kocak, Caglar, and Oztas, 2018) have been used in the previous studies (Mahdiraji et al., 2020: 7). F-BWM was used to evaluate the criteria in this paper. The steps of F-BWM as follows (Guo and Zhao, 2017: 24-26; Ecer and Pamucar, 2020: 6-7):

Step 1. A set of decision criteria is built ($\{c_1, c_2, c_3 \ldots . c_n\}$).

Step 2. DMs determine the best and the worst criteria. DMs do not make any comparison in this step.

Step 3. DMs determine the priority of the best criterion over all the criteria by using the linguistic terms as Table 2 (Guo and Zhao, 2017: 24). The linguistic terms are converted into a TFN, and the fuzzy Best-to-Others vector expressed as: $\tilde{A}_B = (\tilde{a}_{B1}, \tilde{a}_{B2}, \ldots, \tilde{a}_{Bn})$, where $\tilde{a}_{Bj}$ represents priority of the best criterion over the jth criterion (j= 1,2, …., n).

Step 4. DMs determine the priority of all the criteria over the worst criterion by using the linguistic terms as Table 2. The linguistic terms are converted into a TFN, and the fuzzy Others-to-Worst vector expressed as: $\tilde{A}_W = (\tilde{a}_{1W}, \tilde{a}_{2W}, \ldots, \tilde{a}_{nW})$, where $\tilde{a}_{jW}$ represents priority of the jth criterion (j= 1,2, …., n) over the worst criterion.

Table 2: Linguistic Terms and Its Corresponding Value to TFNs

Linguistic terms		**TFNs**
EI:	Equally Importance	(1, 1, 1)
WI:	Weakly Important	(2/3, 1, 3/2)
FI:	Fairly Important	(3/2, 2, 5/2)
VI:	Very Important	(5/2, 3, 7/2)
AI:	Absolutely Important	(7/2, 4, 9/2)

Step 5. The model expressed in Eq. (7) is calculated to obtain optimal fuzzy weights ($\tilde{w}^* = \tilde{w}_1^*, \tilde{w}_2^*, \ldots. \tilde{w}_n^*$) using the Maple software.

$$\min \xi^*$$

$$s.t. \begin{cases} \left| \frac{l_B^w, m_B^w, u_B^w}{l_j^w, m_j^w, u_j^w} - (l_{Bj}, m_{Bj}, u_{Bj}) \right| \leq (k^*, k^*, k^*) \\ \left| \frac{l_j^w, m_j^w, u_j^w}{l_W^w, m_W^w, u_W^w} - (l_{jW}, m_{jW}, u_{jW}) \right| \leq (k^*, k^*, k^*) \\ \sum_{j=1}^{n} R(\tilde{w}_j) = 1 \\ l_j^w \leq m_j^w \leq u_j^w \\ l_j^w \geq 0 \\ j = 1,2, \ldots\ldots, n \end{cases} \quad (7)$$

$\tilde{w}_j = (l_j^w, m_j^w, u_j^w)$ expressed the fuzzy weight of practice j and l_j^w, m_j^w, u_j^w respectively denotes the lower, medium, and upper values of the TFN weights.

Step 6. Consistency Ratio (CR) plays a critical role in checking the consistency degree of the pairwise comparison. It should be noted that CR depends on the priority of the best criterion over the worst criterion. The CR of the comparisons can be calculated using Eq. (8). In this research, CRs less than 0.1 are considered acceptable. The Consistency Index (CI) for the different linguistic terms used in F-BWM is shown in Table 3 (Guo and Zhao, 2017: 26).

$$CR = \frac{\xi^*}{CI} \quad (8)$$

Table 3: CI For F-BWM

Linguistic Terms	**CI**
Equally Importance (EI)	3.00
Weakly Important (WI)	3.80
Fairly Important (FI)	5.29
Very Important (VI)	6.69
Absolutely Important (AI)	8.04

Step 7. Let $a_j = (l_j, m_j, u_j)$ be a TFN. Fuzzy weights are defuzzified by graded mean integration representation (GMIR) as in Eq. (9) (Guo and Zhao, 2017: 24; Ecer and Pamucar, 2020: 6):

$$R\ (a_j) = \frac{1}{6}(l_j + 4m_j + u_j) \quad (9)$$

Case study

At the end of 2018, the textile and clothing sector in Turkey is the first sector which about 15 billion US dollars with the biggest foreign trade surplus. The textile industry, which forms the basis of our existence in global markets, has a special place in the world with the importance it attaches to product quality, designs capable of determining fashion and trends, and high technologies it uses. The textile sector which is one of Turkey's oldest industries is considered an important trading area (www.uib.org.tr). The textile industry is one of the sectors that use digital technologies in supply chain. For this reason, the textile sector was determined as the sector evaluated in this study. DMs consist of three experienced SCM experts. Table 4 shows the priorities of the main criteria and sub-criteria determined by three DMs.

Table 4: The Linguistic Terms for Fuzzy Preferences of Criteria

Main Criteria							
					EC	**EN**	**SO**
DM 1	**BO**	**Best:**		**EC**	EI	WI	VI
	OW	**Worst:**		**SO**	VI	FI	EI
DM 2	**BO**	**Best:**		**EC**	EI	FI	VI
	OW	**Worst:**		**SO**	VI	FI	EI
DM 3	**BO**	**Best:**		**EC**	EI	FI	VI
	OW	**Worst:**		**SO**	VI	WI	EI
Economic Sub-Criteria							
				EC1	**EC2**	**EC3**	**EC4**
DM 1	**BO**	**Best:**	EC1	EI	WI	FI	VI
	OW	**Worst:**	EC4	VI	VI	FI	EI
DM 2	**BO**	**Best:**	EC2	FI	EI	VI	AI
	OW	**Worst:**	EC4	VI	AI	WI	EI
DM 3	**BO**	**Best:**	EC1	EI	WI	VI	AI
	OW	**Worst:**	EC4	AI	VI	WI	EI
Environmental Sub-Criteria							
				EN1	**EN2**	**EN3**	**EN4**
DM 1	**BO**	**Best:**	EN2	WI	EI	FI	AI
	OW	**Worst:**	EN4	VI	AI	WI	EI
DM 2	**BO**	**Best:**	EN1	EI	WI	FI	AI
	OW	**Worst:**	EN4	AI	VI	FI	EI
DM 3	**BO**	**Best:**	EN1	EI	WI	AI	FI
	OW	**Worst:**	EN3	AI	FI	EI	FI
Social Sub-Criteria							
				SO1	**SO2**	**SO3**	**SO4**
DM 1	**BO**	**Best:**	SO1	EI	WI	FI	VI
	OW	**Worst:**	SO4	VI	FI	WI	EI
DM 2	**BO**	**Best:**	SO2	WI	EI	VI	AI
	OW	**Worst:**	SO4	VI	AI	WI	EI
DM 3	**BO**	**Best:**	SO1	EI	FI	VI	FI
	OW	**Worst:**	SO3	VI	FI	EI	WI

The priority of the best criterion over all the criteria and the priority of all the criteria over the worst criterion have been determined by DMs using the linguistic terms as Table 2. It is thought that it will be useful to give an example model which used in this paper. Therefore, the calculation for the linguistic preference made by DM 1 for the main criterion is presented below. The linguistic terms for fuzzy preferences of main criteria determined by DM 1 are shown in Table 4. Table 5 shows the fuzzy best-to-others and fuzzy others-to-worst vectors of main criteria determined by DM 1.

Table 5. The Fuzzy Best-to-Others and Fuzzy Others-to-Worst Vectors

Main Criteria	**Best: C1**		**Worst: C3**	
DM1	**C2**	(0.67,1,1.5)	**C1**	(2.5,3,3.5)
	C3	(2.5,3,3.5)	**C2**	(1.5,2,2.5)

Firstly, linguistic preferences are converted to TFNs as in table 5 then Model (10) calculated with the help of Maple 2020 software.

Min k*
s.t.
$l_1 - 0.67 * u_2 \leq k * u_2$; $l_1 - 0.67 * u_2 \geq -k * u_2$;
$m_1 - 1 * m_2 \leq k * m_2$; $m_1 - 1 * m_2 \geq -k * m_2$;
$u_1 - 1.5 * l_2 \leq k * l_2$; $u_1 - 1.5 * l_2 \geq -k * l_2$;
$l_1 - 2.5 * u_3 \leq k * u_3$; $l_1 - 2.5 * u_3 \geq -k * u_3$;
$m_1 - 3 * m_3 \leq k * m_3$; $m_1 - 3 * m_3 \geq -k * m_3$;
$u_1 - 3.5 * l_3 \leq k * l_3$; $u_1 - 3.5 * l_3 \geq -k * l_3$;
$l_2 - 1.5 * u_3 \leq k * u_3$; $l_2 - 1.5 * u_3 \geq -k * u_3$;
$m_2 - 2 * m_3 \leq k * m_3$; $m_2 - 2 * m_3 \geq -k * m_3$;
$u_2 - 2.5 * l_3 \leq k * l_3$; $u_2 - 2.5 * l_3 \geq -k * l_3$;
$1/6 * l_1 + 4/6 * m_1 + 1/6 * u_1 + 1/6 * l_2 + 4/6 * m_2 + 1/6 * u_2 + 1/6 * l_3 + 4/6 * m_3 + 1/6 * u_3 = 1$;
$l_1 \leq m_1 \leq u_1$; $l_2 \leq m_2 \leq u_2$; $l_3 \leq m_3 \leq u_3$;
$l_1 \geq 0, l_2 \geq 0, l_3 \geq 0, k \geq 0$ (10)

The optimal fuzzy weights of main criteria with regard to DM 1 are as follows:

ξ^*= 0.2360 $\tilde{w}_1^* = (0.4074, 0.4542, 0.5412)$; $\tilde{w}_2^* = (0.\,3124, 0.3675, 0.4497)$; $\tilde{w}_3^* = (0.1643, 0.1643, 0.1799)$. Because $\tilde{a}_{BW} = a_{13} = (2.5, 3, 3.5)$, CI is 6.69 as per Table 3 and CR = 0.2360/6.69 = 0.0352. CR < 0.10 hence CR is acceptable.

Above operations are repeated in a similar way and the optimal fuzzy criteria weights, crisp weights, and CRs for all criteria were calculated using Eq. (7). Table 6 shows the optimal fuzzy criteria weights, crisp weights, and CRs for main criteria. Table 7 shows the optimal fuzzy criteria weights, crisp weights, and CRs for sub-criteria.

Table 6: The Optimal Fuzzy Criteria Weights Crisp Weights and CRs for Main Criteria

Main Criteria	DM 1	DM 2	DM 3	Fuzzy wj	Crisp wj
EC	0.4074, 0.4542, 0.5412	0.4442, 0.5505, 0.5505	0.5297, 0.5481, 0.5760	0.4605, 0.5176, 0.5559	0.51
EN	0. 3124, 0.3675, 0.4497	0.2215, 0.3073, 0.3440	0.2116, 0.2451, 0.3058	0.2485, 0.3067, 0.3665	0.31
SO	0.1643, 0.1643, 0.1799	0.1501, 0.1715, 0.1715	0.1761, 0.1983, 0.2338	0.1635, 0.1781, 0.1951	0.18
	CR: 0.0352	CR: 0.0311	CR: 0.0352		

Table 7: The Optimal Fuzzy Criteria Weights Crisp Weights and CRs of Sub-Criteria

EC	DM 1	DM 2	DM 3	Fuzzy w_j	Crisp w_j
EC1	0.2982, 0.3738, 0.3738	0.2634, 0.2855, 0.3410	0.4115, 0.4154, 0.4714	0.3243, 0.3582, 0.3954	0.36
EC2	0.2669, 0.3252, 0.3652	0.3914, 0.4495, 0.5464	0.2831, 0.3203, 0.4258	0.3138, 0.365, 0.4458	0.37
EC3	0.1504, 0.2086, 0.2309	0.1392, 0.1392, 0.1392	0.1241, 0.1260, 0.1471	0.1379, 0.1579, 0.1724	0.16
EC4	0.1008, 0.1165, 0.1165	0.1109, 0.1109, 0.1270	0.1121, 0.1121, 0.1284	0.1079, 0.1131, 0.1239	0.11
	CR: 0.0311	CR:0.0529	CR: 0.0368		
EN	**DM 1**	**DM 2**	**DM 3**	**Fuzzy wj**	**Crisp wj**
EN1	0.2900, 0.2900, 0.3857	0.3375, 0.3889, 0.4402	0.3714, 0.4123, 0.4617	0.3329, 0.3637, 0.4292	0.37
EN2	0.4032, 0.4032, 0.4365	0.2567, 0.3202, 0.3816	0.2371, 0.2845, 0.3318	0.2990, 0.3359, 0,3833	0.34
EN3	0.1480, 0.1646, 0.2100	0.1622, 0.1834, 0.2348	0.1125, 0.1161, 0.1217	0.1409, 0.1547, 0.1888	0.16
EN4	0.1077, 0.1135, 0.1322	0.1027, 0.1027, 1027	0.1569, 0.1809, 0.2306	0.1224, 0.1323, 0,1551	0.13
	CR:0.0559	CR: 0.0266	CR: 0.0559		
SO	**DM 1**	**DM 2**	**DM 3**	**Fuzzy wj**	**Crisp wj**
SO1	0.3691, 0.3755, 0.4447	0.2831, 0.3203, 0.4258	0.4094, 0.4094, 0.4955	0.3538, 0.3684, 0.4553	0.38
SO2	0.2489, 0.2918, 0.3857	0.4115, 0.4154, 0.4714	0.2241, 0.2374, 0.2892	0.2948, 0.3152, 0.3821	0.32
SO3	0.1595, 0.1642, 0.2065	0.1241, 0.1260, 0.1471	0.1307, 0.1388, 0.1851	0.1384, 0,143, 0.1795	0.15
SO4	0.1384, 0.1384, 0.1667	0.1121, 0.1121, 0.1284	0.1776, 0.1790, 0.2288	0.1427, 0.1431, 0.1746	0.15
	CR: 0.0428	CR: 0.0368	CR: 0.0432		

Table 8 shows global weights and ranking of 12 criteria.

Table 8: Ranking of The Sustainability Dimensions

Main Criteria	Evaluation Criteria	Local Weight	Global Weight	Global Rank
EC (Economic): 0.51	EC1	0.36	0.183	2
	EC2	0.37	0.188	1
	EC3	0.15	0.076	5
	EC4	0.12	0.061	7
EN (Environmental): 0.31	EN1	0.37	0.114	3
	EN2	0.34	0.105	4
	EN3	0.16	0.049	9
	EN4	0.13	0.040	10
SO (Social): 0.18	SO1	0.38	0.068	6
	SO2	0.32	0.057	8
	SO3	0.15	0.027	11
	SO4	0.15	0.027	11

The global weights are obtained by multiplying the local weights with the respective main criteria weights. As seen in Table 8, the first three criteria that have the greatest impact on sustainability are product quality, supply flexibility, green manufacturing, and criteria that have the least impact on sustainability are the rights of stakeholders, employee's development, green logistics. Therefore, it can be inferred that using digital technologies in the supply chain makes a major contribution to the economic dimension of sustainability while its impact on the social dimension is insignificant. There are similar findings in the literature, Awasthi et al. (2018) have handled the supplier selection problem by considering sustainable criteria and revealed economic sustainability more important than social and environmental sustainability. Kusi-Sarpong et al. (2019) highlighted companies give more precedence to economic and environmental sustainability instead of social sustainability. Huq, Stevenson, and Zorzini (2014) revealed that developed countries have focused on social sustainability more than developing countries. As stated in Yawar and Seuring (2017), social dimension of sustainability has not become as important as environmental dimension in the literature. Arslan (2020) has revealed that most papers in the literature primarily focused on environmental sustainability, while social sustainability is under-researched. On the other hand, Sudusinghe and Seuring (2020) proved that there is a positive relationship between social and economic sustainability. Therefore, it can be said that firms should give importance to social sustainability as well as economic and environmental sustainability. Hence, firms will be more successful in sustainability.

Conclusions

Sustainability is one of the contemporary themes of today's world and one of the main issues that managers focus on. On the other hand, utilizing digital technologies in the supply chain dramatically affects the sustainability aspect of a supply chain. In this study, F-BWM as one of the novel approaches of MCDM was used to determine the impact of leveraging digital technologies in the supply chain on 3 basic dimensions (economic, environmental, and social) of sustainability.

According to findings, DSC affects some sub-dimensions of sustainability more and it is seen that these sub-dimensions belong to the economic and environmental main dimensions. Because the most popular digital technologies such as IoT, BDA, AI, etc. of DSC are used with economic and environmental concerns by firms. In addition, firms have not yet adapted to the social sustainability dimension of digital technologies in their SCM processes. When the criteria with the highest level of importance are evaluated respectively, product quality is the most important criterion. Firms can improve product quality using BDA because big data needs to be analysed effectively to increase the quality of products while reducing costs. The second most important criterion is supply flexibility. Firms utilizing digital technologies can improve supply flexibility in different ways. For instance, firms using IoT can provide real-time data, respond quickly to changes hence supply flexibility increases. The third most important criterion is green manufacturing. Firms can increase production efficiency and control energy consumption, emissions utilizing BDA. Furthermore, with AI technologies, it becomes easier to ensure sustainable production.

In this study, the impact of leveraging digital technologies in the supply chain on sustainability has been revealed. The findings can contribute to both managers and future studies in the field of the impact of digital technologies used in the supply chain on sustainability. Moreover, it can be inferred the concept of social sustainability is not given enough importance from obtained findings in this study. In future studies, the impact of digital technologies used on the supply chain on sustainability can be examined in terms of a different MCDM method and/or different sectors and the results can be compared.

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