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Comparative Analysis of Multi-criteria Evaluation of Sustainable Supplier Selection Problem Based on Hesitant Fuzzy Linguistic Term Sets.

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Abstract: *The sustainable supplier selection process requires consideration of multi-criteria evaluations. In recent years, to prevent the hesitation of different linguistic expressions by the decision makers, and to help the selection of the best one as the solution of different alternatives, researchers have been using several methods such as hesitant fuzzy linguistic term sets (HFLTS), hesitant fuzzy linguistic (HFL) VIKOR, HFL TOPSIS, and HFL TODIM. In this paper, the sustainable supplier selection process based on Triple Bottom Line (TBL) approach (economic, environmental, and social dimensions) and the comparative analysis of multi-criteria decision-making problem are evaluated using these different methods. Firstly, the decision-making methodologies for the selection of best alternative are described to determine compromise solutions for a problem with conflicting criteria. Then, an illustrative example from the retail market is presented to compare HFLTS, HFL VIKOR, HFL TOPSIS, and HFL TODIM methods for the supplier selection problem with hesitate fuzzy linguistic information. Consequently, similar results have been obtained despite the differences in calculation algorithms of decision methodologies.*

Keywords: *Sustainable supplier selection, linguistic variables, VIKOR, TODIM, TOPSIS*

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I. INTRODUCTION

Sustainable supply chain management (SSCM) can be described to focus on the TBL approach depend on the sustainable development perspective [1, 2, 3, 4, 5]. Seuring and Müller [4] defined SSCM as “the management of material, information, and capital flows along the supply chain while taking goals from the economic, environmental, and social dimensions of sustainable development”. According to this definition, organizations are responsible for these dimensions to manage their supply chain performance [6]. Because, supplier selection process is one of the key inter-organizational operations for SSCM [7]. The sustainable supplier selection performance metrics including economic, environmental, and social criteria and the appropriate selection methods for the ranking suppliers are nowadays the main concern of the SSCM.

The supplier selection problem is one of the most important issues for the effective sustainable supply chain system [8] to fulfill the organizations’ long term needs with economic, environmental, and social criteria. The supplier selection process is defined as “the specification of suppliers for receiving an organization’s needs at a reasonable cost” [9]. Although this definition has been responded to the needs of organizations in traditional sense, the concept of sustainability has begun to give direction to the activities of supply chain experts and managers. While organizations traditionally consider economic criteria to evaluate the supply chain performance such as cost, quality, flexibility, customer satisfaction, effective risk management, and customer responsiveness etc. [10, 11], many sustainable supplier selection performance factors (environmental, social, and economic) play a vital role for the long-term success of a Supply Chain Management (SCM) [2, 4, 7, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22]. Thus, sustainable supplier selection problem requires the evaluation of suppliers’ performance with respect to the TBL approach.

In order to decide what steps to take for an evaluation of sustainable supply chain and supplier selection, multi-criteria decision-making methods have been used. Büyüközkan and Berkol [16] used Quality Function Deployment approach to design effectively a sustainable supply chain. Ageron et al. [14] designed a questionnaire using a Likert scale to choose the relative importance of sustainability compared to traditional criteria (price, quality, delivery, and service). Bai and Sarkis [15] developed an effective and realistic model using the Grey system and Rough set theory for the sustainable supplier selection. Zailani et al. [21] used regression analysis to determine the influence of SSCM and its performance. Govindan et al. [18] and Amindoust et al. [12] illustrated an evaluation of sustainability performance of suppliers using fuzzy sets theory and fuzzy inference system in multi-criteria decision-making (MCDM) problems respectively. Apart from these, Sanayei et al. [23] proposed an MCDM model based on fuzzy sets theory and 2-tuple linguistic information to deal with the supplier selection problems in the SCM. You et al. [24] and Liao and Xu [25] additionally extended the VIKOR method for the multi-criteria supplier selection problem and service quality of airlines. Zhang and Wei [26] compared the extended VIKOR method and TOPSIS method to evaluate the large (strategic) projects of board of directors with hesitant fuzzy set information. Liao et al. [27] developed a HFL VIKOR method, presented the general procedures of this method and compared with HFL TOPSIS method. Wei et al. [28], proposed a HFL TODIM method based on a score function to evaluate several telecommunication service providers. Nevertheless, HFLTS and interval 2-tuple linguistic VIKOR method are not encountered in the literature to examine implementation of the SSCM and the sustainable supplier selection problem. Separately, the HFLTS, the HFL VIKOR, the HFL TODIM, and the HFL TOPSIS methods have never been compared in the literature to evaluate the sustainable supplier selection problem.

The purpose of this paper is to present a practical application to develop a MCDM framework with a comparative analysis using the HFLTS, the HFL VIKOR, the HFL TODIM, and the HFL TOPSIS methods for the sustainable supplier selection problem based on environmental, social, and economic dimensions. The paper is organized as follows: the second section reviews the principles of the comparative analysis of decision making methodologies, the third section presents the definition of the case study and the principles of the HFLTS, the HFL VIKOR, the HFL TODIM, and the HFL TOPSIS methods to solve the case study of the sustainable supplier selection problem. Finally, last section discusses the findings acquired from the analysis and presents some concluding remarks.

II. THE COMPARATIVE ANALYSIS OF DECISION MAKING METHODOLOGIES

There are many selection and ranking methods for the decision maker to illustrate the MCDM problems and to reach a final decision. VIKOR, TODIM, and TOPSIS methods are useful and practical techniques for the selection of best alternative, for the ranking alternatives, and to determine compromise solutions for a problem with conflicting criteria. In this study, the HFLTS method which is proposed by Rodríguez et al. [29] is used to evaluate sustainability performance of suppliers with environmental, social, and economic concerns and compared with the HFL VIKOR method which is proposed by Opricovic and Tzeng [30], the HFL TOPSIS method which is proposed by Beg and Rashid [31], and the HFL TODIM method which is proposed by Wei et al. [28].

Concerning a given indefinite, uncertain, and shortcoming criterion during the supplier selection process, decision makers often produce different types of assessment information for a certain alternative [24]. Firstly, to handle these different types of assessment information, fuzzy set theory has been successfully implemented for many decision making problems [8]. Although simple fuzzy sets are restricted to the modeling of decision problems in which uncertain linguistic information occurs, various additional fuzzy sets have been proposed in the literature; type 2 fuzzy sets [32], non-stationary fuzzy sets [33], intuitionistic fuzzy sets [34], and hesitant fuzzy sets [35] respectively. Then, a fuzzy linguistic approach is determined as an essential model to explain decision makers' consideration in a qualitative form of real world activities using fuzzy sets theory [36]. However, the fuzzy linguistic approach is limited for the processes of computing with words (computational process) to explain qualitative form of the decision makers' linguistic expressions [31]. Finally, Rodríguez et al. [37] proposed HFLTS to make a deduction from linguistic information by using context-free grammars. This method gives form to the linguistic expressions in decision making when experts hesitate among several linguistic information to express their preferences.

Rodríguez et al. [29] introduced the concept of HFLTS motivated by the idea of hesitant fuzzy set [35]. In some cases, decision makers hesitate among several linguistic expressions when they express their preferences [37]. This method has been applied to different kind of decision making problems such as supplier selection problem [38], to enable the elicitation of linguistic expression by using comparative linguistic expression [29]. To deal with hesitant linguistic information, some preliminary definitions for HFLTS are proposed by Rodríguez et al. [29].

Herrera and Martínez [32] firstly proposed 2-tuple linguistic representation model based on symbolic translation. This model represents the linguistic expressions via a 2-tuple (s, α) where s is a linguistic term and α is a numeric value. Rodríguez et al. [36] used the 2-tuple linguistic representation model introduced by Herrera and Martínez [32] in the aggregation phase. In this basic model, α is called a symbolic translation and restricted between two values such that $\alpha \in [0.5, 0.5)$. Then, Chen and Tai [39] proposed a generalized 2-tuple linguistic model and translation functions to overcome the restriction of this model.

In the process of 2-tuple linguistic representation model, many aggregation operators have been proposed. Herrera and Martínez [32] introduced the 2-tuple arithmetic mean operator, weighted average operator, and ordered weighted aggregation operator (OWA). Viedma et al. [40] proposed 2-tuple linguistic weighted average (TLWA) operator to aggregate the different values considering the different importance of the variables and the decision makers' opinions. But, if the 2-tuples are from different linguistic term sets, $s_i(s_j)$ be a linguistic form of the predefined linguistic term set S, and $\alpha_1(\alpha_2)$ be a symbolic translation, an interval-valued 2-tuple linguistic information, $[(s_i, \alpha_1), (s_j, \alpha_2)]$, could be composed of two linguistic terms and two numbers. Zhang [41] presented the interval 2-tuple linguistic representation model and introduced some aggregation operators with interval-valued 2-tuple linguistic information. We will use the interval 2-tuple linguistic representation model and TLWA operator to aggregate the values apart from the HFLTS method which is proposed by Rodríguez et al. [29].

According to the comparative analysis of the structure of the HFLTS, the HFL VIKOR, the HFL TOPSIS, and the HFL TODIM methods to solve the sustainable supplier selection problem, these decision making methodologies are separated from each other through different calculation methods. Besides the calculation methods, quantifying the relative importance of criteria, determining of weights, consistency check, problem structure, final results; the HFL process, the interval 2-tuple linguistic term sets, and the collective interval 2-tuple linguistic term sets are the same process of these methodologies.

III. THE CASE STUDY

3.1. The definition of problem

Dyllick and Hockerts [42], and Elkington [17] have established a framework of the economic, environmental, and social dimensions of sustainability. Dyllick and Hockerts [42] have also emphasized that all three dimensions of sustainability are essential in the long run to be satisfied simultaneously while economic dimension of sustainability can succeed in the short run. These social, environmental, and economic dimensions must be taken into account for the supplier selection process [14] and integrated to the whole SCM. Thus, these three factors need to be at the forefront of companies' supplier selection process [15].

Suppliers must be carefully selected and evaluated because of their contribution to the organization's performance and their essential role in the SCM [43]. In the traditional supplier selection process, economic criteria are the most important criteria to evaluate the suppliers in the long and short term. Dickson (1966) identified 23 sub-criteria and Weber et al. (1991) found 47 sub-criteria from 76 articles for the vendor selection problem [13].

Jia et al. [44] and Ghadimi and Heavey [20] proposed a framework consists of economic criteria such as cost, quality, on-time delivery (service/delivery), and capability (technical capability) or rejection rate for the sustainable supplier selection problem. Chen et al. [8] similarly selected suppliers by decision makers' assessments under various criteria such as profitability, relationship, technological capability, consistency (quality and deliver), or conflict resolution. Ho et al. [45] analyzed related articles for the supplier selection in the international journals from 2000 to 2008 and concluded that quality, price, delivery, and cost criteria are the most popular measures used in the supplier selection process.

Many authors proposed some new framework based on the TBL approach differently from the traditional economic factors. Sarkis and Talluri [46] categorized economic factors into two sets of strategic groups such as strategic performance metrics and organizational factors to evaluate the suppliers on the lower-level tactical and operational factors. The strategic performance metrics group focused on four major metrics including cost, quality, time, and flexibility similarly to the traditional supplier selection criteria. The organizational factors group focused on three major metrics including culture, technology, and relationship. Chan [11] described supply chain performance measures based on five qualitative measurements such as quality, flexibility, visibility, trust, and innovativeness and two quantitative measurements such as cost and resource utilization measurements. Bai and Sarkis [15] introduced economic factors based on strategic performance measures (cost, quality, time, flexibility, innovativeness) and organizational factors (culture, technology, relationship) for the SSCM.

Environmental supplier selection problems are the main issues [47, 48, 49] to meet the needs of the future generations. Gauthier [50] introduced environmental criteria as resource consumption (energy, raw materials, water) and pollution production (polluting agents, toxic products, waste) according to environmental life cycle assessment to select the suppliers. Bai and Sarkis [15] added "environmental management systems" to the environmental criteria. Bai and Sarkis [15] categorized environmental factors into multiple categories such as environmental performance (resource consumption and pollution production) and environmental practices (pollution prevention and control, and environmental management system). Govindan et al. [18] also developed these environmental criteria adding a new variable named "eco design" for the supplier selection process.

Mani et al. [51] exhibited the supplier selection criteria using social sustainability factors including equity, health and safety, wages, education, philanthropy, human rights, child and bonded labour, housing, and ethics. Gauthier [50] illustrated that social dimensions may be viewed from either internal or external social criteria perspectives. Internal social attributes refer to employment practices such as consideration of employees and health and safety at work; external social criteria regard the relations with contractual stakeholders (suppliers, distributors and clients) and relations with various other stakeholders like local communities.

Organizations and scholars have taken various approaches to address the supplier selection criteria. In this study, a number of factors and measures of the economic, environmental, and social sustainability criteria are summarized in Table 1.

Table 1: Sustainable supplier selection criteria [33, 20, 8, 9].

Sustainability criteria	Sub-criteria
Economic	Cost (C_1)
	Quality (C_2)
	Time (C_3)
	Flexibility (C_4)
	Innovativeness
	Technology (C_5)
	Relationship (C_6)
	Culture (C_7)
Environmental	Pollution production and controls (C_8)
	Eco-design (C_9)
	Environmental management system (C_{10})
	Resource consumption (C_{11})
Social	Employment practices (C_{12})
	Health and safety (C_{13})
	Local communities influence (C_{14})
	Contractual stakeholders influence (C_{15})

3.2. Application of HFLTS to sustainable supplier selection problem

There are several methods to rank the alternatives and to propose a solution to the decision makers about multi-criteria decision making problems. The proposed HFLTS method [36] was applied to a company, which is one of the biggest retail company in Turkey. The company serves to its customers approximately 50.000 different products in various categories. Five decision makers from purchasing department in this company are asked to evaluate the sustainable supplier selection criteria about the five suppliers using their expertise. Decision maker 1 (DM1) and decision maker 2 (DM2) are purchasing experts; decision maker 3 (DM3) is a category manager, decision maker 4 (DM4) is a purchasing assistant, and decision maker 5 (DM5) is a purchasing manager in this company.

There are five possible alternatives: supplier 1 (P1), supplier 2 (P2), supplier 3 (P3), supplier 4 (P4), and supplier 5 (P5). Based on the sustainable supplier selection research, we consider three major criteria and fifteen sub-criteria to evaluate suppliers as shown in Table 2. In this paper, the innovativeness criteria is not considered to evaluate suppliers because the decision makers evaluated the new launch of products and new use of technologies with technology sub-criteria.

The five decision makers selected different linguistic term sets in accordance with Table 2 to evaluate the decision-making criteria. Specifically, DM1 provides his assessments in the set of 5 labels, A; DM2 provides his assessments in the set of 7 labels, B; DM3 provides his assessments in the set of 9 labels, C; DM4 provides his assessments in the set of 5 labels, D; and DM5 provides his assessments in the set of 5 labels, E. In addition, each decision maker rated the relative importance of each criterion with a set of 5 linguistic term set, F.

Table 2: The defined linguistic term sets for decision makers.

Type	Number	Linguistic variables.
A	5	a0=Very low(VL) a1=Low(L) a2=Medium(M) a3=High(H) a4=Very high(VH)
B	7	b0=Very low(VL) b1=Low(L) b2=Medium low(ML) b3=Medium(M) b4=Medium high(MH) b5=High(H) b6=Very high(VH)
C	9	c0=Exremely low(EL) c1=Very low(VL) c2=Low(L) c3=Medium low(ML) c4=Medium(M) c5=Medium high(MH) c6=High (H) c7= Very high(VH) c8=Extremely high(EH)
D	5	d0=Very low(VL) d1=Low(L) d2= Medium(M) d3=High(H) d4=Very high(VH)
E	5	e0=Very low(VL) e1=Low(L) e2= Medium(M) e3=High(H) e4=Very high(VH)
F	5	f0=Very unimportant(VI) f1= Unimportant(U) f2=Medium(M) f3=Important(I) f4=Very important(VI)

Suppose that; there are I decision makers DMk (k=1, 2,…,l), m alternatives Ai (i=1,2,…,m), and n evaluation criteria Cj (j=1,2,…,n) in a sustainable supplier selection problem. Each decision maker DMk has a weight $\lambda_k > 0$ (k=1,2,…,l) satisfying $\sum_{k=1}^{l} \lambda_k = 1$, and the weight express the relative importance of decision maker in the decision-making group. In addition, decision makers may use different linguistic term sets to express their assessments. The linguistic term sets may be used together with context-free grammar such as “at most”, “between (b/w)”, or “at least” etc.

The procedure for the hesitant fuzzy linguistic term sets [36] and its practice in the case can be defined as the following steps:

Step 1. The semantics and syntax of the linguistic term sets are defined for decision makers, which is shown in Table 3.

Step 2. The context-free grammar GH and the elements of the $G_H = (V_N, V_T, I, P)$ are defined as [36].

Step 3. The preference relations pk provided by experts $k \in \{1,2,\dots,m\}$ are gathered for both criteria and alternatives. The assessments of the five alternatives on each criterion are presented in Table 3 and the criteria weights provided by the five decision makers using hesitant linguistic term sets are presented in Table 4.

Table 3: Assessments that are provided by the decision makers

		C_1	C_2	C_3
DM_1	P_1	VH	VH	at least H
	P_2	at least H	VH	H
	P_3	at least M	H	at least H
	P_4	at least M	b/w M and H	b/w L and M
	P_5	H	b/w M and H	b/w M and H
DM_2	P_1	At least H	at least MH	at least H
	P_2	At least MH	at least MH	at least H
	P_3	at least H	at least MH	at least H
	P_4	b/w MH and H	b/w ML and MH	b/w ML and M
	P_5	b/w MH and H	b/w L and M	b/w L and ML
DM_3	P_1	at least VH	at least VH	b/w H and VH
	P_2	at least VH	at least H	b/w H and VH
	P_3	at least VH	at least H	b/w MH and VH
	P_4	b/w MH and H	b/w M and H	b/w L and M
	P_5	b/w ML and M	b/w L and ML	b/w ML and M
DM_4	P_1	VH	at least H	VH
	P_2	at least H	at least H	at least H
	P_3	at least H	at least M	at least H
	P_4	at least H	b/w M and H	L
	P_5	b/w M and H	b/w L and M	b/w M and H
DM_5	P_1	VH	VH	at least H
	P_2	VH	VH	H
	P_3	M	VH	at least H
	P_4	at least H	b/w M and H	L
	P_5	M	b/w L and M	at most L

Table 4: Assessments of criteria weights.

	Decision makers	DM1	DM2	DM3	DM4	DM5
Criteria	C_1	VI	VI	VI	VI	VI
	C_2	I	I	VI	I	I
	C_3	I	VI	VI	VI	VI
	C_4	I	VI	I	M	I
	C_5	VI	VI	VI	VI	I
	C_6	VI	VI	VI	VI	I
	C_7	VI	I	M	I	VI
	C_8	VI	I	M	VI	I
	C_9	I	M	VI	I	VI
	C_{10}	I	I	I	M	I
	C_{11}	I	VI	I	M	VI
	C_{12}	I	I	I	I	VI

C_{13}	VI	M	M	VI	VI
C_{14}	I	M	VI	M	VI
C_{15}	M	I	U	I	I

Step 4. The preference relations are transformed into HFLTS by using the transformation function E_{G_H}. The assessments of the five alternatives on each criteria provided by decision makers are transformed the preference relations into HFLTS by using the transformation function E_{G_H} introduced as follows.

Table 3: Continue…

		C_4	C_5	C_6	C_7	C_8	C_9	C_{10}	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}
DM_1	P_1	H	VH	VH	VH	at least H	at least H	VH	H	VH	at least H	VH	at least H
	P_2	b/w M and H	at least H	at least H	VH	b/w M and H	b/w M and H	at least H	b/w M and H	at least H	at least H	b/w M and H	H
	P_3	b/w M and H	H	VH	VH	at least H	at least H	at least H	at least M	at least H	at least H	VH	H
	P_4	b/w L and M	b/w M and H	b/w L and M	at least M	b/w L and M	at most L	b/w M and H	at most L	at least H	b/w M and H	at most L	at most L
	P_5	b/w L and H	b/w L and M	b/w M and H	at least M	at most L	b/w L and M	at most L	at most L	at least H	M	at least H	L
DM_2	P_1	b/w MH and H	VH	at least H	VH	b/w M and H	at least H	b/w M and MH	b/w MH and H	b/w MH and H	MH	at least MH	b/w M and MH
	P_2	MH	VH	at least H	VH	b/w M and MH	MH	b/w ML and M	b/w M and MH	b/w M and MH	b/w ML and MH	b/w M and H	b/w ML and MH
	P_3	H	VH	at least H	at least H	b/w M and H	at least H	b/w ML and M	b/w M and H	b/w MH and H	b/w M and H	at least MH	b/w M and MH
	P_4	b/w ML and M	b/w ML and M	b/w MH and H	b/w L and ML	b/w ML and M	ML	b/w ML and M	b/w L and ML	b/w ML and M	b/w L and ML	at most L	b/w L and M
	P_5	L	b/w L and M	b/w M and MH	at most L	L	VL	at most L	at most L	b/w M and MH	b/w L and ML	b/w ML and MH	b/w L and M
DM_3	P_1	b/w MH and H	at least VH	at least VH	at least VH	at least H	at least VH	b/w MH and VH	b/w MH and H	b/w MH and H	b/w M and H	at least VH	H
	P_2	b/w H and VH	b/w H and VH	at least VH	at least VH	b/w M and MH	at least VH	b/w MH and H	at least VH	b/w M and MH	b/w H and VH	at least VH	MH
	P_3	b/w MH and H	at least VH	EH	at least VH	b/w H and VH	at least H	b/w H and VH	at least VH	b/w MH and H	b/w H and VH	at least VH	H
	P_4	b/w VL and ML	b/w ML and M	M	b/w MH and H	ML	b/w L and ML	b/w ML and M	b/w VL and L	b/w L and ML	b/w ML and MH	b/w L and ML	MH
	P_5	b/w VL and ML	L	b/w ML and M	b/w ML and M	VL	b/w VL and ML	b/w VL and L	b/w VL and L	b/w VL and ML	b/w ML and MH	VL	EH
DM_4	P_1	VH	at least H	VH	VH	at least H	VH	at least H	H	H	at least H	VH	at least M
	P_2	VH	at least M	at least H	at least H	b/w M and H	H	H	M	b/w M and H	H	at least H	at least H
	P_3	VH	at least H	VH	VH	at least H	VH	at least M	b/w M and H	at least H	at least M	b/w M and H	at least H
	P_4	at most L	b/w L and M	at least M	b/w M and H	b/w L and M	b/w L and M	at most L	at most M	b/w L and M	H	L	b/w L and H
	P_5	b/w L and M	b/w L and M	at least H	b/w L and M	M	at most L	VL	at most L	b/w L and M	L	b/w L and M	at most L
DM_5	P_1	at least M	at least H	VH	at least H	at least H	at least M	H	b/w M and H	at least H	b/w M and H	b/w M and H	b/w L and M
	P_2	at least H	H	at least H	at least H	at least H	b/w M and H	VH	at least M	H	at least H	at least H	b/w L and H
	P_3	at least H	at least H	at least H	at least H	at least H	at least H	at least H	at least M	at least H	at least M	at least H	at least M
	P_4	b/w L and H	L	M	b/w L and M	b/w L and M	at most L	L	at most M	b/w L and M	at most M	at most L	b/w L and M
	P_5	at most M	at most M	at least H	at most L	b/w L and M	at most L	at most L	b/w L and M	at most L	b/w L and M	b/w L and M	at most L

Let EGH be a function that transforms comparative linguistic expressions, $II \in S_{II}$, obtained by GH, into HS. S is the linguistic term set used by GH.

$$E_{G_H} = S_{II} \to H_S \qquad (1)$$

Step 5. The envelope Hs, $env(H_S) = [H_{S-}, H_{S+}]$, is obtained for each HFLTS. The assessments of the five alternatives on each criteria provided by decision makers are obtained for each HFLTS its envelope, $env(H_S) = [H_{S-}, H_{S+}]$, by means of its upper and lower bound introduced as follows:

$$env(H_S) = [H_{S-}, H_{S+}], \quad H_{S-} \leq H_{S+} \qquad (2)$$

Step 6. The linguistic decision matrix $D_k = \left(d_{ij}^k\right)_{mxn}$ is converted into interval 2-tuple linguistic decision matrix $\tilde{R}_k = \left(\tilde{r}_{ij}^k\right)_{mxn} = \left(\left[\left(r_{ij}^k, 0\right), \ \left(\alpha_{ij}^k, 0\right)\right]\right)_{mxn}$, where $r_{ij}^k, \alpha_{ij}^k \in S, S = \{s_i | i = 0,1,2, \dots, g\}$ and $r_{ij}^k \leq \alpha_{ij}^k$. The linguistic decision matrix is converted into interval 2-tuple linguistic decision matrix $\tilde{R}_k = \left(\left[\left(r_{ij}^k, 0\right), \left(\alpha_{ij}^k, 0\right)\right]\right)_{5x15}$.

Step 7. In the aggregation phase, we use the arithmetic mean aggregation operator based on 2-tuple linguistic information. The aggregated 2-tuple linguistic weight vector $\hat{w} = \left((w_1, \alpha_{w1}), (w_2, \alpha_{w2}), \dots, \right.$ $wn\alpha wnT$is determined by aggregating the criteria weights provided by decision makers, where

$$\left(w_j, \alpha_{wj}\right) = \Delta\left(\sum_{k=1}^{l} \lambda_k \, \Delta^{-1}\left(w_j^k, 0\right)\right), \qquad (3)$$

and the collective interval 2-tuple linguistic decision matrix $\hat{R} = \left(\hat{r}_{ij}\right)_{mxn} = \left[\left(r_{ij}, \alpha_{ij}\right)\right]_{mxn}$ is constructed by aggregating the decision makers' opinions, where

$$\left(r_{ij}, \alpha_{ij}\right) = \Delta\left(\sum_{k=1}^{l} \lambda_k \, \Delta^{-1}\left(r_{ij}^k, \alpha_{ij}^k\right)\right), \qquad (4)$$

Let $\hat{w} = \left((w_1, \alpha_{w1}), (w_2, \alpha_{w2}), \dots, \ (w_n \alpha_{wn})\right)^T$ be their associated 2-tuple weights, the 2-tuple linguistic weighted average (TLWA) operator is defined as follows [24]:

$$TLWA\ (X) = \Delta\left(\frac{\sum_{i=1}^{n}\Delta^{-1}(w_i,\alpha_{wi}).\Delta^{-1}(r_i,\alpha_i)}{\sum_{i=1}^{n}\Delta^{-1}(w_i,\alpha_{wi})}\right) \qquad (5)$$

and the evaluations of the five alternatives are aggregated. The collective 2-tuple linguistic weighted average decision matrix $\tilde{R} = \left(\tilde{r}_{ij}\right)_{mxn} = \left[\left(r_{ij}, \alpha_{ij}\right)\right]_{5x15}$ is determined.

Step 8. The pessimistic and optimistic collective preference relations, PC,PC+, are obtained by using the linguistic aggregation operator φ, and the pessimistic and optimistic collective preference for each alternative are computed by using the linguistic aggregation operator as follows:

$$P_{\mathrm{i}}{}^{+} = \Delta\left(\emptyset\left(\Delta^{-1}(r_1^{+}, \alpha_1^{+})\right)\right), \qquad (6)$$

$$P_{\mathrm{i}}{}^{-} = \Delta\left(\emptyset\left(\Delta^{-1}(r_1^{-}, \alpha_1^{-})\right)\right). \qquad (7)$$

and a vector of intervals $V^R - (P_1^R, P_2^R, P_3^R, P_4^R)$ of collective preferences for the alternatives is built in Table 5.

Table 5: Pessimistic and optimistic preference for each alternative.

Suppliers	Pessimistic	Optimistic
P1	[(b3,-0.030)	(b6,-0.060)]
P2	[(b3,-0.040)	(b5,-0.0233)]
P3	[(b3,-0.00)	(b5,0.0366)]
P4	[(b1,0.0233)	(b4,-0.0066)]
P5	[(b1,-0.0366)	(b3,0.060)]

Step 9. The preference relation PD, the preference degree of A over B and the preference degree of B over A, is built as follows:

$$P(A > B)\ \frac{max\ (0,a_2\ \ b_1)\quad max\ (0,a_1\ \ b_2)}{(a_2\ \ a_1) + (b_2\ \ b_1)} \qquad (8)$$

$$P(B > A)\ \frac{max\ (0,b_2\ \ a_1)\quad max\ (0,b_1\ \ a_2)}{(a_2\ \ a_1) + (b_2\ \ b_1)} \qquad (9)$$

The preference relation PD is shown in Table 6.

Table 6: Preference relation PD.

Suppliers	P1	P2	P3	P4	P5
P1	0.00	0.59	0.52	1.00	1.00
P2	0.41	0.00	0.43	1.00	1.00
P3	0.48	0.57	0.00	1.00	1.00
P4	0.00	0.00	0.00	0.00	0.60
P5	0.00	0.00	0.00	0.40	0.00

Step 10. The non-dominance choice degree NDD is applied as follows:

NNDi $min\{1\quad p_{ji}^{s},\ j\ \ 1, \dots, n, j \neq i\}$ (10)

where $p_{ji}^{s} - max\ \{p_{ji} - p_{ij}, 0\}$

NDD is shown for the alternatives as follows:

NDD P1 = 1.00, NDD P2 = 0.82, NDD P3 = 0.95, NDD P4 = 0.00, NDD P5 = 0.00

The set of alternatives and the selected best one is ranked above. In this study, the alternative P_1 selected by the model is chosen by the decision makers.

$$P_1 > P_3 > P_2 > P_4 = P_5$$

3.3. Application of HFL VIKOR method to sustainable supplier selection problem.

Opricovic [52] originally introduced the VIKOR method for the multi-criteria optimization of complex systems. This method ranks and selects the most appropriate solution from a set of alternatives with conflicting criteria to reach a final decision for the decision makers [30]. The most appropriate ranking alternative could be selected by the measurement of closeness to the ideal solution [53].

The VIKOR method has been investigated by many scholars and applied to the multi-criteria decision making problems [24, 54]. Opricovic and Tzeng [30] determined the weight stability intervals, and extended the VIKOR method with a stability analysis and trade-offs analysis.

In this section, we present a hesitant fuzzy linguistic VIKOR method to solve the multi-criteria sustainable supplier selection problem because this method can help the decision makers to reach a final decision with conflicting criteria [53]. A multi-criteria decision-making problem includes many criteria and some of them are conflicting. In this study, the criteria values, which are the sustainable supplier selection metrics, are determined according to the HFLTS and take the form of 2-tuple linguistic information. HFLTS provide decision makers a greater flexibility to elicit linguistic preferences using context-free grammars [36].

In this section, the first seven steps are the same steps with previous HFLTS method to reach collective 2-tuple linguistic decision matrix $\hat{R} = \left(\hat{r}_{ij}\right)_{mxn} = \left[\left(r_{ij}, \alpha_{ij}\right)\right]_{mxn}$. So, the rest of the procedure for the HFL VIKOR method and its practice in the case can be defined as the following steps:

Step 8. The positive ideal solution (r+) and negative ideal solution (r-) are determined as follows:

$$r^{+} = [(r_1^{+}, \alpha_1^{+}), (r_2^{+}, \alpha_2^{+}), \dots, (r_n^{+}, \alpha_n^{+})], \qquad (11)$$

$$r^{-} = [(r_1^{-}, \alpha_1^{-}), (r_2^{-}, \alpha_2^{-}), \dots, (r_n^{-}, \alpha_n^{-})], \qquad (12)$$

Where

$$\left(r_j^{+}, \alpha_j^{+}\right) = \begin{Bmatrix} \max_i\left\{\left(r_{ij}^{k}, \alpha_{ij}^{k}\right)\right\}, & for\ benefit\ criteria \\ \min_i\left\{\left(r_{ij}^{k}, \alpha_{ij}^{k}\right)\right\}, & for\ cost\ criteria \end{Bmatrix}, \qquad (13)$$

$$\left(r_j^{-}, \alpha_j^{-}\right) = \begin{Bmatrix} \min_i\left\{\left(r_{ij}^{k}, \alpha_{ij}^{k}\right)\right\}, & for\ benefit\ criteria \\ \max_i\left\{\left(r_{ij}^{k}, \alpha_{ij}^{k}\right)\right\}, & for\ cost\ criteria \end{Bmatrix}, \quad (14)$$

While decision makers evaluate the alternatives, they assume that cost is a cost criterion and the rest of all criteria are benefits criteria.

Step 9. The 2-tuples (S_i, α_i), (R_i, α_i), (Q_i, α_i), i=1,2,…,m, are computed using the following equations, respectively:

$$(S_i, \alpha_i) = \Delta\left(\sum_{j=1}^{n} \frac{\Delta^{-1}(w_j,\alpha_{wj}).\left(\Delta^{-1}\left(r_j^{+},\alpha_j^{+}\right)-\Delta^{-1}\left(r_{ij}^{k},\alpha_{ij}^{k}\right)\right)}{\sum_{j=1}^{n}\Delta^{-1}(w_j,\alpha_{wj}).\left(\Delta^{-1}\left(r_j^{+},\alpha_j^{+}\right)-\Delta^{-1}\left(r_j^{-},\alpha_j^{-}\right)\right)}\right) \quad (15)$$

$$(R_i, \alpha_i) = \Delta\left(\max_j\left(\frac{\Delta^{-1}(w_j,\alpha_{wj}).\left(\Delta^{-1}\left(r_j^{+},\alpha_j^{+}\right)-\Delta^{-1}\left(r_{ij}^{k},\alpha_{ij}^{k}\right)\right)}{\sum_{j=1}^{n}\Delta^{-1}(w_j,\alpha_{wj}).\left(\Delta^{-1}\left(r_j^{+},\alpha_j^{+}\right)-\Delta^{-1}\left(r_j^{-},\alpha_j^{-}\right)\right)}\right)\right) \qquad (16)$$

$$(Q_i, \alpha_i) = \Delta\left(v\frac{\Delta^{-1}(S_i,\alpha_i)-\Delta^{-1}(S^{*},\alpha^{*})}{\Delta^{-1}(S^{-},\alpha^{-})-\Delta^{-1}(S^{*},\alpha^{*})} + (1-v)\frac{\Delta^{-1}(R_i,\alpha_i)-\Delta^{-1}(R^{*},\alpha^{*})}{\Delta^{-1}(R^{-},\alpha^{-})-\Delta^{-1}(R^{*},\alpha^{*})}\right) \qquad (17)$$

where $(S^{*}, \alpha^{*}) = \min_i\left(S_{i,}\alpha_i\right)$, $(S^{-}, \alpha^{-}) = \max_i\left(S_{i,}\alpha_i\right)$, $(R^{*}, \alpha^{*}) = \min_i\left(R_{i,}\alpha_i\right)$, $(R^{-}, \alpha^{-}) = \max_i\left(R_{i,}\alpha_i\right)$. The value of v is set to 0.5 in this study.

The 2-tuples (S_i, α_i), (R_i, α_i), (Q_i, α_i) respectively are calculated by Eqs. (15),(16) and (17) and the results are shown as follows:

(S_i, α_i)=[(b1,-0.0381), (b1,0.0602), (b1,-0.0039), (b4,0.0721), (b5,-0.0162)],

(R_i, α_i)=[(b0,0.0178), (b0,0.0295), (b0,0.0233), (b1,-0.0878), (b1,-0.0794)],

(Q_i, α_i)=[(b0,0.0000), (b1,-0.0111), (b0,0.0646), (b5,0.0494), (b6,0.0000)]

Step 10. The alternatives are ranked by sorting the 2-tuples $(S_i, \alpha_i), (R_i, \alpha_i)\ and\ (Q_i, \alpha_i)$. The results are three ranking lists as shown in Table 7.

Table 7: The ranking of the five alternatives by (S_i, α_i), $(R_i, \alpha_i), and\ (Q_i, \alpha_i)$

			Suppliers		
	P1	P2	P3	P4	P5
Si	1	3	2	4	5
Ri	1	3	2	4	5
Qi	1	3	2	4	5

The alternative (P1) is proposed as a compromise solution by the measure $\min_i\left(Q_{i,}\alpha_i\right)$. Finally, the set of alternatives is ordered, and we selected the best one as the solution to the GDM problem. In this study, the alternative P_1 (first supplier) selected by the hesitant fuzzy linguistic VIKOR method is chosen by the decision makers.

$$P_1 > P_3 > P_2 > P_4 > P_5$$

3.4. Application of HFL TOPSIS method to sustainable supplier selection problem

Hwang and Yoon [55] proposed TOPSIS method to identify solution from a set of finite alternatives. This method is a popular approach for the MCDM problems to select the best alternative which should have the shortest distance from the positive ideal solution and the furthest distance from the negative ideal solution [56]. The Euclidean distance is used to evaluate the relative closeness of alternatives to the ideal solution [57]. Triantaphyllou and Lin [57] developed the fuzzy version of the TOPSIS method for decision making problems illustrating fuzzy version of the positive ideal solution, the negative ideal solution, and the relative closeness to the ideal solution of the alternatives. Beg and Rashid [31] extended fuzzy TOPSIS for HFLTS with the opinion of finite decision makers about the criteria of alternatives and calculated the distance between two HFLTS with the help of envelops of HFLTS.

In this section, the first seven steps are the same steps with previous HFLTS method to reach collective 2-tuple linguistic weighted average decision matrix $\tilde{R} = (\tilde{r}_{ij})_{mxn} = [(r_{ij}, \alpha_{ij})]_{5x15}$, because the sustainable supplier selection metrics are determined according to the HFLTS and the form of 2-tuple linguistic information, and the evaluations of the five alternatives are aggregated using 2-tuple weights. The rest of the procedure for the HFL TOPSIS method [30] and its practice in the case can be defined as the following steps :

Step 8. The positive ideal solution (A+) and negative ideal solution (A-) are determined as follows:

$$A^+ = \begin{bmatrix} \begin{pmatrix} \left(\left(max_{i=1}^{k}\left(\overset{max}{i}\{(r_{ij}^{k}, \alpha_{ij}^{k})\}\right)\right)\right) | j\epsilon\Omega_b, \\ \left(\left(min_{i=1}^{k}\left(\overset{min}{i}\{(r_{ij}^{k}, \alpha_{ij}^{k})\}\right)\right)\right) | j\epsilon\Omega_c, \end{pmatrix}, \\ \begin{pmatrix} \left(\left(max_{i=1}^{k}\left(\overset{max}{i}\{(r_{ij}^{k}, \alpha_{ij}^{k})\}\right)\right)\right) | j\epsilon\Omega_b, \\ \left(\left(min_{i=1}^{k}\left(\overset{min}{i}\{(r_{ij}^{k}, \alpha_{ij}^{k})\}\right)\right)\right) | j\epsilon\Omega_c, \end{pmatrix} \end{bmatrix} \quad (18)$$

$$A^+ = (V_1^+ V_2^+ \ldots . V_n^+)$$

$$A^- = \begin{bmatrix} \begin{pmatrix} \left(\left(min_{i=1}^{k}\left(\overset{min}{i}\{(r_{ij}^{k}, \alpha_{ij}^{k})\}\right)\right)\right) | j\epsilon\Omega_b, \\ \left(\left(max_{i=1}^{k}\left(\overset{max}{i}\{(r_{ij}^{k}, \alpha_{ij}^{k})\}\right)\right)\right) | j\epsilon\Omega_c, \end{pmatrix}, \\ \begin{pmatrix} \left(\left(min_{i=1}^{k}\left(\overset{min}{i}\{(r_{ij}^{k}, \alpha_{ij}^{k})\}\right)\right)\right) | j\epsilon\Omega_b, \\ \left(\left(max_{i=1}^{k}\left(\overset{max}{i}\{(r_{ij}^{k}, \alpha_{ij}^{k})\}\right)\right)\right) | j\epsilon\Omega_c, \end{pmatrix} \end{bmatrix} \quad (19)$$

$$A^- = (V_1^- V_2^- \ldots . V_n^-)$$

While decision makers evaluate the alternatives, Ω_b is the collection of benefit criteria and Ω_c is the collection of cost criteria.

Step 9. The positive ideal separation matrix D+ and negative ideal separation matrix D- computed using the following equations, respectively;

$$D^+ = \begin{bmatrix} d(x_{11}, V_1^+) + & d(x_{12}, V_2^+) + & \ldots & d(x_{1n}, V_n^+) \\ d(x_{21}, V_1^+) + & d(x_{22}, V_2^+) + & \ldots & d(x_{2n}, V_n^+) \\ \vdots & \vdots & & \vdots \\ . & . & & . \\ d(x_{m1}, V_1^+) + & d(x_{m2}, V_2^+) + & \ldots & d(x_{mn}, V_n^+) \end{bmatrix} \quad (20)$$

and

$$D^- = \begin{bmatrix} d(x_{11}, V_1^-) + & d(x_{12}, V_2^-) + & \ldots & d(x_{1n}, V_n^-) \\ d(x_{21}, V_1^-) + & d(x_{22}, V_2^-) + & \ldots & d(x_{2n}, V_n^-) \\ \vdots & \vdots & & \vdots \\ . & . & & . \\ d(x_{m1}, V_1^-) + & d(x_{m2}, V_2^-) + & \ldots & d(x_{mn}, V_n^-) \end{bmatrix} \quad (21)$$

The positive ideal separation matrix D+ and negative ideal separation matrix D- respectively are calculated by Eqs. (20) and (21).

Step 10. The relative closeness (RC) of each alternative to the ideal solution are calculated as follows:

$$RC = \frac{D_i^-}{D_i^+ + D_i^-}, \quad (22)$$

where $D_i^- = \sum_{j=1}^{n} d(x_{ij,} V_j^-)$ and $D_i^+ = \sum_{j=1}^{n} d(x_{ij,} V_j^+)$.

The relative closeness of each alternatives are shown as follows:

RC= (0.93; 0.81; 0.87; 0.20; 0.13)

According to this closeness coefficient RC, final result would be

$P_1 > P_3 > P_2 > P_4 > P_5$.

P1 is the best alternative in the HFL TOPSIS method like as the HFL VIKOR method.

3.5. Application of HFL TODIM method to sustainable supplier selection problem

The TODIM method is proposed by Gomes and Lima [58] to solve the MCDM problems. This method is based on prospect theory of Kahneman and Tversky [59] in 1979. Zhang and Xu [60] described that in the classical TODIM approach, "the prospect value function is first built to measure the dominance degree of each alternative over the others, which reflects the decision makers' behavioural characteristic such as reference dependence and lose aversion, and then the overall value of each alternative is calculated and whereby the ranking of alternatives can be obtained". Wei et al. [28] extended the TODIM approach for HFLTS to solve the MCDM problems to manage the hesitation of the decision makers using HFLTS and computed the dominance degree for each alternative by using a prospect value function.

In this method, the first seven steps are the same steps with previous HFLTS method to reach collective 2-tuple linguistic decision matrix $\hat{R} = (\hat{r}_{ij})_{mxn} = [(r_{ij}, \alpha_{ij})]_{mxn}$. The rest of the HFL TODIM procedure [28] and its practice in the case can be defined with the following additional steps:

Step 8. While decision makers evaluate the alternatives, the cost criteria are transformed into benefit criteria by normalizing the 2-tuple linguistic decision matrix $\hat{R} = (\hat{r}_{ij})_{mxn} = [(r_{ij}, \alpha_{ij})]_{mxn}$ to yield a normalized 2-tuple linguistic decision matrix $G = (g_{ij})_{mxn} = [(r_{ij}, \alpha_{ij})]_{mxn}$. The dominance degrees $\varphi_j(p_{i,}p_k)$ of the alternatives p_i $(i = 1, \dots, m)$ are calculated over the alternatives p_k $(k = 1, \dots, m)$ concerning each criterion cj as follows:

$$\varphi_j(p_{i,}p_k) = \begin{cases} \sqrt{\dfrac{w_{jr} d_{gd}(g_{ij,} g_{kj})}{\sum_{j=1}^{n} w_{jr}, \qquad if\ \mathbb{F}(g_{ij}) - \mathbb{F}(g_{kj}) > 0;}} \\ 0, \qquad if\ \mathbb{F}(g_{ij}) - \mathbb{F}(g_{kj}) = 0; \\ -\dfrac{1}{\theta}\sqrt{\dfrac{\left(\sum_{j=1}^{n} w_{jr}\right) d_{gd}(g_{kj,} g_{ij})}{w_{jr}}}, \quad if\ \mathbb{F}(g_{ij}) - \mathbb{F}(g_{kj}) < 0; \end{cases} \qquad (23)$$

where $w_r = max\{w_j | j = 1,2, \dots, n\}$ and the Euclidean distance between g_{ij} and g_{kj} is computed as follows:

$$d_{gd}(g_{ij}, g_{kj}) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{|g_{ij} - g_{kj}|}{\tau + 1}\right)^2} \qquad (24)$$

Step 9. The dominance degrees $\delta(p_{i,}p_k)$ of the alternatives p_i $(i = 1, \dots, m)$ are calculated over the alternatives p_k $(k = 1, \dots, m)$ as follows:

$$\delta(p_i, p_k) = \sum_{j=1}^{n} \varphi_j(p_{i,}p_{k).} \qquad (25)$$

The dominance degrees $\delta(p_{i,}p_k)$ of the alternatives are shown in Table 8.

Table 8: The dominance degrees $\delta(p_{i,}p_k)$ of the alternatives.

	P1	P2	P3	P4	P5
P1	0.00	-0.56	-5.25	2.52	2.68
P2	-13.73	0.00	-11.91	2.30	2.48
P3	-7.53	-3.58	0.00	2.41	2.61
P4	-38.10	-34.84	-36.82	0.00	-3.40
P5	-40.60	-37.63	-39.99	-15.14	0.00

Step 10. The overall dominance degrees $\xi(p_i)$ of the alternatives p_i $(i = 1, \dots, m)$ are calculated as follows:

$$\xi(p_i) = \frac{\sum_{k=1}^{m} \delta(p_i, p_k) - min_i\{\sum_{k=1}^{m} \delta(p_i, p_k)\}}{max_i\{\sum_{k=1}^{m} \delta(p_i, p_k)\} - min_i\{\sum_{k=1}^{m} \delta(p_i, p_k)\}} \qquad (26)$$

The overall dominance degrees $\xi(p_i)$ of the alternatives are shown as follows:

$\xi(p_i)$=(1.00; 0.85; 0.96; 0.15; 0.00)

The alternatives according to the overall dominance degrees are ranked as follows and the alternative P_1 (first supplier) selected by the HFL TODIM method is chosen by the decision makers like as the HFL VIKOR and HFL TOPSIS method :

$$P_1 > P_3 > P_2 > P_4 > P_5$$

IV. CONCLUSION

In this paper, we have selected the best supplier based on sustainable criteria to solve a multi-criteria decision-making problem with a real application of retail market. We applied the HFLTS and the 2-tuple linguistic representation model to estimate the information of uncertainty situations for the decision makers' assessments. The experts in the retail market evaluated the best supplier with sustainable criteria with the use of a context-free grammar. The considered criteria were prioritized using interval 2-tuple fuzzy linguistic approach and the alternatives were evaluated with respect to the criteria using the HFLTS, HFL-VIKOR, HFL-TOPSIS, and HFL-TODIM methods. When these methods were used, similar results have been obtained despite the differences in calculation algorithms of decision methodologies. According to the results, the alternative P_1 (first supplier) was selected the best one as the solution to the multi-criteria decision-making problem by these methods. The set of alternatives was ranked as $P_1 > P_3 > P_2 > P_4 > P_5$. On the other hand, the results obtained with HFLTS method, the alternative P_4 equals the alternative P_5, are separated from the other methods. Consequently, in the comparative analysis of sustainable supplier selection process by using HFLTS, HFL-VIKOR, HFL-TOPSIS, and HFL-TODIM methods, basic characteristic of multi-criteria decision-making methods have been displayed, and the evaluation of the alternatives show that these methods are available to reduce the vague, imperfect, and imprecise information for the decision-making process.

Distance and similarity measures for HFLTS might be investigated and be developed with some more aggregation operators such as induced OWA operators, generalized OWA operators to support the proposed model in the future research.

REFERENCES

[1] C. R. Carter and D. S. Rogers, A framework of sustainable supply chain management: moving toward new theory, International Journal of Physical Distribution & Logistics Management, Vol. 38, Iss: 5, (2008), 360 – 387.

[2] M. Pagell and Z. Wu, Building a more complete theory of sustainable supply chain management using case studies of 10 exemplars, Journal of Supply Chain Management, 45 (2009), 37-56.

[3] S. Gold, S. Seuring and P. Beske, Sustainable supply chain managementand inter-organizational resources: a literature eview, Corporate Social Responsibility and Environmental Management, 17 (2010), 230-245.

[4] S. Seuring and M. Müller, From a literature review to a conceptual framework for sustainable supply chain management, Journal of Cleaner Production, 16 (2008a), 1699–1710.

[5] S. Seuring and M. Müller, Core issues in sustainable supply chain management – a Delphi study, Business Strategy and the Environment, 17 (2008b), 455-466.

[6] H. Walker and N. Jones, Sustainable supply chain management across the UK private sector, Supply Chain Management: An International Journal, 17/1 (2012), 15–28.

[7] G. Büyüközkan and G. Çifçi, A novel fuzzy multi-criteria decision framework for sustainable supplier selection with incomplete information, Computers in Industry, 62 (2011), 164-174.

[8] C. T. Chen, C. T. Lin and S. F. Huang, A fuzzy approach for supplier evaluation and selection in supply chain management, International Journal of Production Economics, 102 (2006), 289-301.

[9] C. Kahraman, U. Cebeci and Z. Ulukan, Multi-criteria supplier selection using fuzzy AHP, Logistics Information Management, 16 (2003), 382-394.

[10] B. M. Beamon, Supply chain design and analysis: models and methods, International Journal of Production Economics, 55 (1998), 281-294.

[11] F. T. S. Chan, Performance measurement in a supply chain, International Journal of Advanced Manufacturing Technology, 21 (2003), 534–548.

[12] A. Amindoust, S. Ahmed, A. Saghafinia and A. Bareininejad, Sustainable supplier selection: a ranking model based on fuzzy inference system, Applied Soft Computing, 12 (2012), 1668-1677.

[13] A. H. Azadnia, M. Z. M. Saman and K. Y. Wong, Sustainable supplier selection and order lot-sizing: an integrated multi-objective decision-making process, International Journal of Production Research, 53 (2015), 383-408.

[14] B. Ageron, A. Gunasekaran and A. Spalanzan, Sustainable supply management: an empirical study, International Journal of Production Economics, 140 (2012), 168–182.

[15] C. Bai and J. Sarkis, Integrating sustainability into supplier selection with grey system and rough set methodologies, International Journal of Production Economics, 124 (2010), 252–264.

[16] G. Büyüközkan and Ç. Berkol, Designing a sustainable supply chain using an integrated analytic network process and goal programming approach in quality function deployment, Expert Systems with Applications, 38 (2011), 13731–13748.

[17] J. Elkington, Partnerships from cannibals with forks: the triple bottom line of 21st century business, Environmental Quality Management, 8.1 (1998), 37-51.

[18] K. Govindan, R. Khodaverdi and A. Jafarian, A fuzzy multi criteria approach for measuring sustainability performance of a supplier based on triple bottom line approach, Journal of Cleaner Production, 47 (2013), 345-354.

[19] K. S. Jauhar, M. Pant and M. C. Nagar, Differential evolution for sustainable supplier selection in pulp and paper industry: a DAE based approach, Computer Methods in Materials Science, 15 (2015), 118-126.

[20] P. Ghadimi and C. Heavey, Sustainable supplier selection in medical device industry: toward sustainable manufacturing, 21st CIRP Conference on Life Cycle Engineering, (2014), 165-170.

[21] S. Zailani, G. Jeyaraman, K. Vengadasan and R. Premkumar, Sustainable supply chain management (SSCM) in Malaysia: a survey, International Journal of Production Economics, 140 (2012), 330–340.

[22] V. Jayaraman, R. Klassen and J. D. Linton, Sustainable supply chains: An introduction, Journal of Operations Management, 25 (2007), 1067-1382.

[23] A. Sanayei, S. F. Mousavi and A. Yazdankhah, Group decision making process for supplier selection with VIKOR under fuzzy environment, Expert Systems with Application, 37 (2010), 24–30.

[24] X. Y. You, J. X. You, H. C. Liu and L. Zhen, Group multi-criteria supplier selection using an extended VIKOR method with interval 2-tuple linguistic information, Expert Systems with Applications, 42 (2015), 1906-1916.

[25] H. Liao and Z. Xu, A VIKOR-based method for hesitant fuzzy multi-criteria decision making, Fuzzy Optimistic Decision Making, 12 (2013), 373-392.

[26] N. Zhang and G. Wei, Extension of VIKOR method for decision making problem based on hesitant fuzzy set, Applied Mathematical Modelling, Vol. 37, Issue 7 (2013), 4938–4947.

[27] H. Liao, Z. Xu and X. J. Zeng, Hesitant fuzzy linguistic VIKOR method and its application in qualitative multiple criteria decision making, IEEE Transactions on Fuzzy Systems, 23 (2015), 1343-1355.

[28] C. Wei, Z. Ren and R. M. Rodríquez, A hesitant fuzzy linguistic TODIM method based on a score function, International Journal of Computational Intelligence Systems, 8:4 (2015), 701-712.

[29] R. M. Rodríguez, R. D. A. Calle, T. G. Arteaga and L. Martínez, A fuzzy envelope for hesitant fuzzy linguistic term sets based on Choquet integral, Proceedings of the 10th International FLINS Conference, (2012), 52-57.

[30] S. Opricovic and G. H. Tzeng, Extended VIKOR method in comparison with outranking methods, European Journal of Operational Research, 178 (2007), 514–529.

[31] I. Beg and T. Rashid, TOPSIS for hesitant fuzzy linguistic term sets, International Journal of Intelligent Systems, Vol. 28 (2013), 1162–1171.

[32] F. Herrera and L. Martínez, A 2-tuple fuzzy linguistic representation model for computing with words. IEEE Transactions on Fuzzy Systems, Vol. 8 No. 6. (2000), 746-752.

[33] J. M. Garibaldi, M. Jaroszewski and S. Musikasuwan, Nonstationary fuzzy sets, IEEE Transactions on Fuzzy Systems, 16 (2008), 1072-1086.

[34] K. T. Atanassov, Intuitionistic fuzzy sets, Fuzzy Sets and Systems, 20 (1986), 87-96.

[35] V. Torra, Hesitant fuzzy sets, International Journal of Intelligent Systems, 25 (6) (2010), 529–539.

[36] R. M. Rodríquez, L. Martínez and F. Herrera, A group decision making model dealing with comparative linguistic expressions based on hesitant fuzzy linguistic term sets, Information Sciences, 241 (2013), 28–42.

[37] R. M. Rodríquez, H. Liu and L. Martínez, A fuzzy representation for the semantics of hesitant fuzzy linguistic term sets, Foundations of Intelligent Systems, Advances in Intelligent Systems and Computing, Springer-Verlag Berlin Heidelberg, 2014, 277.

[38] H. Liu and R. M. Rodríguez, A fuzzy envelope for hesitant fuzzy linguistic term set and its application to multicriteria decision making, Information Sciences, 258 (2014), 220-238.

[39] C. T. Chen and W. S. Tai, Measuring the intellectual capital performance based on 2-tuple fuzzy linguistic information, The 10th Annual Meeting of APDSI, Asia Pacific Region of Decision Sciences Institute, Vol. 20, 2005.

[40] H. E. Viedma, F. Herrera, L. Martínez, J. C. Herrera and A. G. Lopez, Incorporating filtering techniques in a fuzzy linguistic multi-agent model for information gathering on the web, Fuzzy Sets and Systems, 148 (2004), 61 – 83.

[41] H. Zhang, The multiattribute group decision making method based on aggregation operators with interval-valued 2-tuple linguistic information, Mathematical and Computer Modelling, 56 (2012), 27–35.

[42] T. Dyllick and K. Hockerts, Beyond the business case for corporate sustainability, Business Strategy and the Environment, 11 (2002), 130.

[43] D. J. Bowersox, D. J. Closs, T. P. Stank and S.B. Keller, Integrated supply chain logistics makes a difference, Supply Chain Management Review, 4 (2000), 70–79.

[44] P. Jia, K. Govindan, T. M. Choi and S. Rajendran, Supplier selection problems in fashion business operations with sustainability considerations, Sustainability, 7 (2015), 1603-1619.

[45] W. Ho, X. Xu and P. K. Dey, Multi-criteria decision making approaches for supplier evaluation and selection: A literature review, European Journal of Operational Research, 202 (2010), 16-24.

[46] J. Sarkis and S. Talluri, A model for strategic supplier selection, The Journal of Supply Chain Management, 38.1 (2002),18.

[47] D. Kannan, K. Govindan and S. Rajendran, Fuzzy Axiomatic Design approach based green supplier selection: a case study from Singapore, Journal of Cleaner Production, 96 (2015), 194-208.

[48] P. K. Humphreys, Y. K. Wong and F. T. S. Chan, Integrating environmental criteria into the supplier selection process, Journal of Materials Processing Technology, 138 (2003), 349-356.

[49] R. J. Kuo, Y. C. Wang and F. C. Tien, Integration of artificial neural network and MADA methods for green supplier selection, Journal of Cleaner Production, 18 (2010), 1161-1170.

[50] C. Gauthier, Measuring corporate social and environmental performance: the extended life-cycle assessment, Journal of Business Ethics, 59 (2005), 199–206.

[51] V. Mani, R. Agrawal and V. Sharma, Supplier selection using social sustainability: AHP based approach in India, International Strategic Management Review, 2 (2014), 98-112.

[52] S. Opricovic, Multicriteria optimization of civil engineering systems. Faculty of Civil Engineering, Belgrade, 2.1 (1998), 5-21.

[53] S. Opricovic and G. H. Tzeng, The Compromise solution by MCDM methods: a comparative analysis of VIKOR and TOPSIS, European Journal of Operational Research, 156 (2) (2004), 445–455.

[54] H. C. Liu, L. Liu and J. Wu, Material selection using an interval 2-tuple linguistic VIKOR method considering subjective and objective weights, Material and Design, 52 (2013), 158-167.

[55] C. L. Hwang and K. Yoon, Multiple attribute decision making: methods and applications, Springer-Verlag, New York, 1981.

[56] B. Ashtiani, F. Haghighirad, A. Makui and G. Montazer, Extension of fuzzy TOPSIS method based on interval-valued fuzzy sets, Applied Soft Computing, 9 (2009), 457-461.

[57] E. Triantaphyllou and C. T. Lin, Development and evaluation of five fuzzy multiattribute decision-making methods, International Journal of Approximate Reasoning, Vol. 14, Issue 4 (1996), 281-310.

[58] L. F. A. M. Gomes and M. M. P. P. Lima, TODIM: basics and application to multicriteria ranking of projects with environmental impacts, Found. Comput. Decis. Sci. 16 (1991), 113–127.

[59] D. Kahneman and A. Tversky, Prospect theory: an analysis of decision under risk, Econometrica, Vol. 47, No. 2. (1979), 263-292.

[60] X. Zhang and Z. Xu. The TODIM analysis approach based on novel measured functions under hesitant fuzzy environment, Knowledge-Based Systems, Vol. 61 (2014), 48–58.

Oguzhan Yavuz. "Comparative Analysis of Multi-criteria Evaluation of Sustainable Supplier Selection Problem Based on Hesitant Fuzzy Linguistic Term Sets." International Journal of Business and Management Invention(IJBMI) 6.7 (2017): 67-78.