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Research Article

Minimizing OHS Risks with Spherical Fuzzy Sets as a Verdict to Inventory Management: A Case Regarding Energy Companies

Burcu Yılmaz Kaya

Industrial Engineering Department, Faculty of Engineering, Gazi University, Ankara 06570, Turkey

Correspondence should be addressed to Burcu Yılmaz Kaya; burcuyilmaz@gazi.edu.tr

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As one of the vital ergonomics operations, occupational health and safety (OHS) measures are important for each and every production environment. Furthermore, the severity of adverse impacts or occurrence probability of OHS risks can be much higher, especially for particular companies dealing with hazardous or dangerous materials or products. Although eminent instances exist in the OHS literature, studies linking OHS to operational supply chain management (SCM) activities and aim to embed ergonomics sentiment into decision procedures in a way that reduces OHS risks are unfortunately lacking in the literature. In this point of view, a novel approach grounding on inventory control aiming OHS risk minimization was developed, and a case study regarding a gas distribution energy company was performed as demonstration. Integrated ABC-VED matrix was developed and employed to handle the inventory management problem by emphasizing OHS risks' influence as well as proposing cost-effective solutions, while spherical fuzzy sets (SFS) and simple additive weighting (SAW) method were used to enlighten the best SCM-related decisions in terms of ABC-VED results, to minimize the OHS risks of maintenance employees and possible adverse impacts on human health. Three different actors participated as decision makers (DMs) by the employment of SFS-SAW group decision making approach, where computed categories and delineated research outcomes were scrutinized in details by benchmarking of the results in terms of varying DM assessments and supplier company driven inventoried item groups, where sensitivity analysis on overall results were also performed. 103 out of 270 items of a protoset were analyzed, a subset of 51 items listed in Category I was determined to be used in further analysis. Illustrative explanations of diversification of criteria weighting scores regarding different parties in the decision making process were also presented with several schematic representations of research outcomes in the light of multidimensional benchmarking debates.

1. Introduction

Ergonomics, or human factors engineering, is defined by International Ergonomic Association [1] as "the scientific discipline concerned with an understanding of interactions among humans and other elements of a system, and the profession that applies theory, principles, data, and methods to design to optimise human well-being and overall system performance." The origin of the word *ergonomics* goes back to very ancient as it is accepted as a comibation of two Greek words *ergon* and *nomos*, meaning *work* and *laws* [1–3]. Since the fundamentals of ergonomics science ground on providing safe, convenient, and bareable working environment in regards to safety measures and physical health and well-being of employees, occupational health and safety (OHS) is an eminent key in ergonomics applications area for each and every organization performing in all kind of industries. Albeit the advanced measurement methods' and technologically enhanced tools' success, OHS activities are generally focused on the basic control of individuals' behaviours or emerging physical risks related to the environment or job design; which consequence in prosperous achievements in the OHS framework but unfortunately is not able to be sprat into organization-wide through being embedded in management philosophy.

The required components, materials, goods, and services must be provided at the right time, in the right quantity, in the right condition, and at a reasonable price from the right source for each organization; nevertheless, it has more crucial importance for energy companies to continue their operations uninterruptedly and without any immerse impact on human health and life. To obtain this challenging balance is a real quest, where effective business-to-business (B2B) management with their suppliers might be regarded as the main key for success in terms of securing prosperous supply chain management (SCM) operations. Especially for energy companies, who have to purchase varying component parts, products, or raw materials from multiple suppliers operating in many different channels and geographical regions, protecting employees from occupational health and safety (OHS) risks and ensuring that necessary precautions are taken in their interactions with any possible dangerous or hazardous work environment element closely related to the ability to construct and manage the right supply process, as well as identification and implementation of occupational health practices.

In the 21st century, changes in the business environment have contributed to the importance of the B2B relationship management and attracted bigger attention to "supply chain networking." Especially for organizations such as energy companies that need to use a large number of OHS-related products and parts in everyday practices, the management of the channels through which these products are purchased directly determines the OHS levels that can be provided at best.

According to some researchers, supply chain network structures are accepted as new organizational forms under the names of "Keiretsu," "Extended Enterprise," "Virtual Company," "Global Production Network," and "Next Generation Production System" [4]. Regardless of which name is used, companies that want to work with zero error and zero work accidents should plan the procurement, purchase, inventory, and implementation of products, parts, and raw materials that are critical to OHS risks and to cause harm to human health, not only in a cost-effective way but also in a way that minimizes possible OHS risks.

As a part of B2B management and SCM operations, the selection of appropriate suppliers among many suppliers with various potential and competencies is a multicriteria decision-making (MCDM) problem [5]. The complexity of the decision problem will increase with the severity level of the investigated items as with OHS-related matters, and on top of that, numerous conflicting, vague, and challenging criteria will structure the decision space to choose the most appropriate supplier with the aims of reducing purchasing costs along with product delivery time, and simultaneously increasing profits, customer satisfaction, and brand's competitiveness strength.

Inventory management is a systematic approach to the purchase, storage, and sale of raw materials and finished products [6]. Basically, two different main inventory types could be encountered; finished product inventory serves as a substitute for production capacity and can be regarded as stored production capacity, like energy stored in batteries; in contrast, input inventories (raw materials, components, or subassemblies) aim to prevent production inertia and are therefore complementary to production capacity as they increase effective capacity. Regardless of the type of stock in the company, the process should be handled with an effective inventory management approach in-line with organizational targets and strategical goals.

Inventory management approaches indicate scientific ways to designate what to order, when to order, and how much to order, and how much to stock so that purchasing costs and storing costs are kept as low as possible. It helps to protect the organization against the fluctuation in supply and demand, uncertainty, and minimize waiting time [6]. The inventory management process involves monitoring and controlling inventory as it moves from your suppliers to your warehouse and then to your customers, and this particular major SCM problem type receives considerable attention in the related literature. In lieu of this attention, existing research had mostly focused on the financial aspects, where the relation between inventory management and nonfinancial performance of an organization, e.g., its impact on OHS activities remained unclear [7]. However, ergonomics discipline has been studied for a long time and has been practised with successful human factors analysis methods and tools in varying industries to make systems humane, operate smoothly, and increase performance and efficiency levels in many different operational activities; it is a fatal shortcoming of the related existing literature that the necessary link between OHS activities and SCM has not been adequately established in order to take decisions with the effect of ergonomic factors regarding operational SCM activities such as inventory management.

In this study, a novel approach aiming at the elimination or minimization of OHS risks was proposed through inventory control practices in order to simultaneously reduce risks and provide a cost-effective solution ensuring that the company can maintain its competitiveness regarding ergonomics standpoint and SCM management issues without any interruptions or pitfalls in manufacturing and delivery processes. Integrated ABC-VED analysis was employed to determine the item group with utmost relation to cause possible OHS risks and dangers and the highest investment percentages. 103 items out of 270 to be purchased and 197 to be inventoried were categorized, and 51 items were designated to be in Category I into this end. A group decision-making approach was adopted to highlight different perspectives regarding diverse problem space dimensions, as well as, spherical fuzzy sets (SFSs) were used to represent the impact of linguistic judgements and vagueness of the decision problems on the results. After identification of the main items subset and identification of influencing elements, the simple additive weighting (SAW) method was used to further investigate the OHS-SCM problem space as a robust, user-friendly, and potent technique.

In this context, the contribution of this study to the existing literature can be summarized as hereinafter;

(i) OHS risk minimization problem was examined in relation to SCM and inventory management as an attempt to contemplate the influence of human factors strategically from a macro point of view, rather than through tactical applications.

(ii) Risks and uncertainties existing in the decision process were revealed and considered.

(iii) Integrated ABC-VED analysis was introduced and firstly employed for an energy company and OHS-related items as a pioneer study to the related literature.

(iv) SFS was introduced to inventory management literature.

(v) ABC-VED and SFS-SAW methods were used as a first in a study of OHS risk minimization research topic.

(vi) Criteria importance levels representing their influences on B2B relationship management regarding inventory control strategies aiming OHS risk minimization were delineated, and results were benchmarked corresponding to different item groups prior to companies acting in the energy sector.

(vii) Sensitivity analysis was performed with different scenarios to address the robustness of the proposed approach and reliability of the study outcomes.

The remainder of this study is as follows: the surveys performed on the pillars topics of the study were presented under the literature review section. The handled problem was stated, ABC analysis, VED analysis, SFS linguistic terms and mathematical operations, and the proposed approach were introduced under the section of materials and methods. Sensitivity analysis outcomes and obtained results and findings were presented and scrutinized in detail under the results and discussion section, where corollary deductions on the essence of the work were portrayed under the managerial insights and practical implications section. The conclusion section provides the summarization of the study and points out related future research directions in the end.

2. Literature Review

The literature review research related to the pillars of this study was presented under three subsections regarding the studies related to inventory management and inventory control methods and integrated ABC-VED method and applications, studies handling OHS risk assessment and inventory management problems simultaneously, and studies that employed SFS linguistic terms in OHS risk assessment problems.

2.1. Survey of Related Work on Inventory Management and ABC-VED Method. The fundamental factors to be considered decisive in inventory management processes for energy companies are costs and the criticality of the inventoried items [8]. As being the most frequently used inventory management technique in both scholarly researches and field practices, there exist an eminent and immense number of studies of inventory management problems carried out with the ABC method. From this standpoint, introducing existing instances on the basis of application fields or the methods in which they are used together might provide a more understandable and easy-to-follow presentation, and be in the interest of the readers. As examples of recent studies, Partovi and Anandarajan [9] and Banharnsakun [10] employed the artificial neural network (ANN) method for upgrading ABC classification, Ramanathan [11] proposed a novel weighted linear optimization model, where Nallusamy et al. [12] employed more traditional approaches such as MRP techniques, quantity-based discounts methods, or classical optimization models. There are some studies that employed MCDM techniques with ABC analysis, for instance, Simunovic et al. [13] and Kabir and Hasin [14] compared several inventory classification models with analytical hierarchy process (AHP) method and AHP-TOPSIS methods, respectively. With similar approaches and applications, Gupta and Kant [15], Devnani et al. [16], Gupta et al. [17], Vaz et al. [18], Devnani et al. [19], Anand et al. [6], Mahatme et al. [20], Wandalkar et al. [21], Pirankar et al. [22], Kumar and Chakravarty [8], Singh et al. [23], Antonoglou et al. [24], Ceylan and Bulkan [25], and Durmuş and Duğral [26] employed ABC and VED analysis integrally.

Among various selective inventory control techniques such as EOQ (economic order quantity) [8, 16–18, 20–34], VED (vital, essential, desirable) [6, 8, 17–19, 21–25, 35–37], FSN (fast-moving, slow-moving, non-moving) [30, 37, 38], SDE (scarce, difficult-to-procure, easily-available) [39], XYZ [32], safety stock (SS) [39], vendor-managed-inventory (VMI) [38, 40], and reorder point (ROP) [39] methods, each organization should manage this process by applying one or more stock control methods in accordance with the operating market and core- and side-activities to be carried out. Since the integrated computation matrix considers both the critical values and the economic and importance levels of items, the integrated ABC-VED analysis is the most frequently used method to address the optimal budget regarding the criticality levels and required amounts [6, 8, 15–22, 27, 29–35, 37, 41–44].

As the integrated ABC-VED analysis allows practitioners to ensure critical items and never go out of stock on those while minimizing the costs, this method found a very particular audience in health practices and has acquired a very wide application area in the related literature regarding drug center, pharmacy, and hospital management problems [4–36, 39, 41].

2.2. Survey of Related Work on OHS and Inventory Management. Although OHS and inventory management issues are in close interaction with each other, the current literature is far from meeting the need in this regard when the number of studies on the subject and the scope of these studies were considered.

As one of the scarce instances, Fan and Zhou [7] underlined the connection between OHS performance and the supply-demand mismatch of an organization. They developed an approach grounding on the normal accident theory (NAT) and return-on-assets (ROAs) method to investigate productivity pressure on safety issues, and practised a case study for textile manufacturers. The authors analyzed the correlation between supply-demand mismatch levels and a higher likelihood of safety incidents; a more salient impact was found regarding more complex (labor intensive) and tightly coupled (high production capacity utilization) operation environments.

The other instance of this topic handled an inventory management system articulation. Crouse et al. [45] designed an online barcode-based inventory control and tracking system for a chemical industry company to be able to track hazardous items and employees to be engaged with them more accurately and efficiently, as well as, suggesting a waste management system for the hazardous materials operating on the developed inventory management system.

As for the entailed research methods, although its vast application in so many valuable researches on health management-related decision problems, the ABC-VED method has not been used in decisions related to OHS management, or has not been employed in a study with OHS risks minimization aims, to the best of our knowledge. This occasion addresses a serious gap in the current literature that needs to be closed quickly, since this particularly suitable method for companies is attaining more attention than any other one to its activities related to OHS, i.e., energy companies have not been used yet in such a case study regarding the inventory process management of highly critical items to OHS-related risk and dangerous occurrences.

2.3. Survey of Related Work on OHS and SFS Applications. As a relatively new method, the application examples of SFS linguistic terms in problems related to OHS topics are also limited. The existing research instances employed SFS with anMCDM method to embrace the verbal judgements and accurately represent the assessments of decision makers (DMs) at best.

Sharaf and Khalil [46] employed the TOmada de Decisão Interativa e Multicritério (TODIM) method with SFS to the supplier selection problem. The authors practised a case study on selecting green OHS equipment suppliers with the SFS-TODIM method, and subsequently used the Technique of Order Preference by Similarity to an Ideal Solution (TOPSIS) and the VIsekriterijumska optimizacija i KOmpromisno Resenje (VIKOR) methods with SFS to compare the computation outcomes and examine the effect of the attenuation factor of losses on the solution.

In another example, Liu et al. [47] developed an OHS risk assessment framework by integrating the TODIM and Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) methods with SFS, and determined the priorities related to the identified OHS hazards for medical staff of a hospital.

2.4. Research Gap. As a result of the performed literature review, surveys on the study pillar topics are classified and presented to the readers in Table1, hereinafter.

As Table 1 indicates, there is an explicit need to make a connection between OHS risk minimization and inventory management topics in the related literature. Most of the existing inventory management studies employed ABC-VED integrated matrices with cost minimization and deficiency prevention objectives for critical items, whereas any existing study performed on inventory management topic did not focus on OHS risk minimization to the best of our knowledge neither with the integrated ABC-VED method nor any other inventory management techniques. There are two studies which were focused on the relationship between OHS safety levels and SCM activities through supplier selection problem considering OHS equipment employing SFS to represent the vagueness of the problem, where none of them employed the SFS-SAW method as MCDM techniques as well as both did not investigate the relationship between inventory management activities and supplier selection decisions, hence did not perform an additional study to this end and did not predicate the latter decision problem's input data into that results. Furthermore, where the integrated ABC-VED method was frequently used especially in health-care related industries and application areas, surprisingly, surveys indicated that it has never been used in the energy industries to the best of our knowledge, while the risk of occupational accidents in this industry is very high and the possible consequences could be very destructive.

As a consequence, studies focusing on the relationship between ergonomic OHS risk minimization and SCM inventory control and tracking topics would help to enrich the existing literature and shed light on scientific researchers, ergonomists, and field practitioners interested in OHS activities, inventory management, human factors engineering, and SCM. This study aims to close the abovementioned major gaps of the related literature, while it suggests new application instances of an SFS-MCDM method and managerial strategies developed upon the obtained computation results and sensitivity analysis for a pristine application area, the energy industry.

3. Materials and Methods

3.1. Problem Statement. A novel integrated approach was proposed for handling the OHS risk minimization problem within this study. This novel approach firstly applies an integrated ABC-VED analysis to be able to ensure taking into account the severity levels of the necessary items in order to eliminate or minimize the OHS risks, in the meantime, the cost factors were not ignored to ensure organizational survival, through handling the inventory management problem, then, the integrated SFS-SAW method was used to efficiently manage the uncertainty existing in the decision process and determine the importance and performance levels related to the decision parameters. Furthermore, obtained results were further investigated subsequently and sensitivity analyses were performed, and grounding on the outcomes of these solution elicitation operations OHS risk minimization strategies were developed through a B2B relationship management perspective for the group that should be followed closely among the listed inventoried items. The general illustration of the operation flow of the proposed approach is represented in Figure 1.

The consecutive stages of the proposed approach, computation substeps and activities, and general operation mechanism of the proposed approach were explained later in this section with their finest details, where the schematic representation of the investigated system and developed solution approach are also presented in Figure 2, so that the

Table 1: Classification of literature survey summary.

Reference	Problem content			Objective	Methodologies			Case study
	Inv. Man.	OHS	Uncertainty		Inventory management	MCDM	Other	
Crouse et al. [45]	✓	✓	—	Safety and waste	—	—	Barcode based tracking system	Chemical industry
Gupta and Kant [15]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Thawani et al. [27]	✓	—	—	Cost and criticality	ABC-VED, EOQ	—	—	Drug store
Gupta et al. [17]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Vaz et al. [18]	✓	—	—	Cost	ABC-VED	—	—	Hospital
Devnani et al. [16]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Nigah et al. (2010)	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Mahatme et al. [20]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Anand et al. [6]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Wandalkar et al. [21]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Borle et al. [28]	✓	—	—	Cost and criticality	ABC-VED, EOQ	—	—	Drug store
Ben Hmida et al. [30]	✓	—	—	Cost and criticality	ABC, VED, FSN	—	—	Oilfield equipment industry
Pirankar et al. [22]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Singh et al. [23]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Stoll et al. [31]	✓	—	—	Criticality	ABC-VED, XYZ	AHP	—	Manufacturing industry
Kumar and Chakravarty [8]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Kant et al. [32]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Gupta and Krishnappa [33]	✓	—	—	Cost and criticality	ABC-VED	—	—	Dental hospital
Antonoglou et al. [24]	✓	—	—	Cost and criticality	ABC-VED	—	—	Military hospital
Ceylan and Bulkan [25]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Subratha et al. [34]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Fakhrzad and Lotfi [38]	✓	—	✓	Time, cost, quality and environment	VMI	—	Mixed integer linear programming	Hospital
Fan and Zhou [7]	✓	✓	—	Safety	—	—	NAT-ROA	Textile industry
Hazrati et al. [35]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital pharmacy
Hussain et al. [41]	✓	—	—	Cost and criticality	ABC-VED	—	—	Hospital
Mishra and Mohanty [37]	✓	—	—	Cost and criticality	ABC, VED, FSN	—	—	Numerical example
Sharaf and Khalil [46]	—	✓	✓	Importance and performance	—	TODIM, VIKOR, TOPSIS	SFS	Numerical example
Pholpipattanaphong and Ramingwong [39]	✓	—	—	Cost and criticality	ABC-VED, EOQ, SS, ROP	—	—	Hospital pharmacy

Table 1: Continued.

Reference	Problem content			Objective	Methodologies			Case study
	Inv. Man.	OHS	Uncertainty		Inventory management	MCDM	Other	
Prommarat and Santiteerakul [42]	✓	—	—	Cost and criticality	ABC-VED	—	—	Drug store
Mor et al. [43]	✓	—	—	Cost and criticality	ABC-VED	—	—	Manufacturing industry
Liu et al. [47]	—	✓	✓	Risk assessment	—	TODIM, PROMETHEE	SFS	Hospital
Durmuş and Duğral [26]	✓	—	—	Cost	ABC-VED	—	—	Hospital
Gizaw and Jemal [36]	✓	—	—	Cost and criticality	ABC-VED, FSN	—	—	Drug store
Annie et al. [29]	✓	—	—	Cost	ABC-VED, EOQ	—	—	Food industry
Atakay et al. [44]	✓	—	—	Cost and criticality	ABC-VED	AHP	OptQuest—ARENA	Automotive industry
Lotfi et al. [40]	✓	—	✓	Cost	VMI	—	Non-linear programming	Hospital
Singh et al. (2022)	✓	—	—	Cost and criticality	—	—	—	Literature review
This research	✓	✓	✓	Cost, criticality, safety and performance	ABC-VED	SAW	SFS	Energy industry

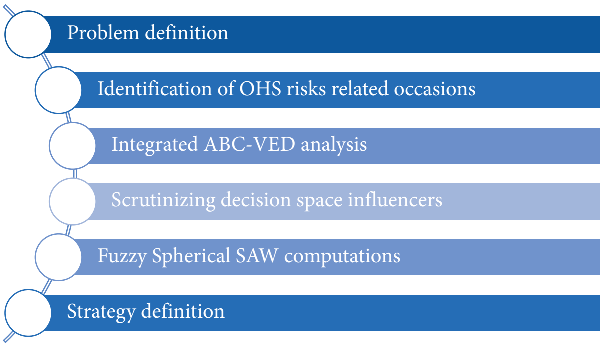

Figure 1: General operation flow of the proposed approach.

readers can better understand the implementation mechanism and interaction with the decision environment of the proposed novel approach.

The company carries out its current SCM operational management (OM) activities solely in regards to the experience of DMs and cost-effective solutions, where this situation often could result in the emergence of OHS risks and hazards in lieu of high deficiency ratios or late delivery than declared lead times of purchased items. The proposed approach aims to provide DMs with competent and effective solutions in practice through simultaneously considering OHS risk minimization, various conflicting factors affecting the decision problem, and the uncertainties to improve the existing OHS, SCM, and OM processes.

As another gaining targeted to be yielded, the proposed approach employs the group decision-making method, and sensitivity analyses reflecting the influence of diverse perspectives on the solution space dimensions were also performed with six different scenarios.

3.2. Notation List

3.2.1. Sets (Indices)

i: Index of inventory item $i \in I = (1, 2, ..., i)$

j: Index of supplier $j \in J = (1, 2, ..., m)$

t: Index of scenario $t \in T = (1, 2, ..., t)$

f: Index of run $f \in F = (1, 2, ..., f)$

e: Index of calculation universes $e \in E = (1, 2)$

q: Index of elements of pth spherical fuzzy set $q \in Q = (u, r)$

p: Index of spherical fuzzy sets $p \in P = (A, B)$

d: Index of DMs $d \in D = (1, 2, ..., d)$

k: Index of criteria $k \in K = (1, 2, ..., n)$.

3.2.2. Parameters

E_e: calculation universe e

P: spherical fuzzy set P

$\mu_{\tilde{A}_s}(u)$: the membership function value of element q to spherical fuzzy set P

$\nu_{\tilde{A}_s}(u)$: the nonmembership function value of element q to spherical fuzzy set P

$\pi_{\tilde{A}_s}(u)$: the hesitancy degree of element q to spherical fuzzy set P

k: scalar value

$S(\tilde{w}_k)$: the spherical weighted importance value of criteria k

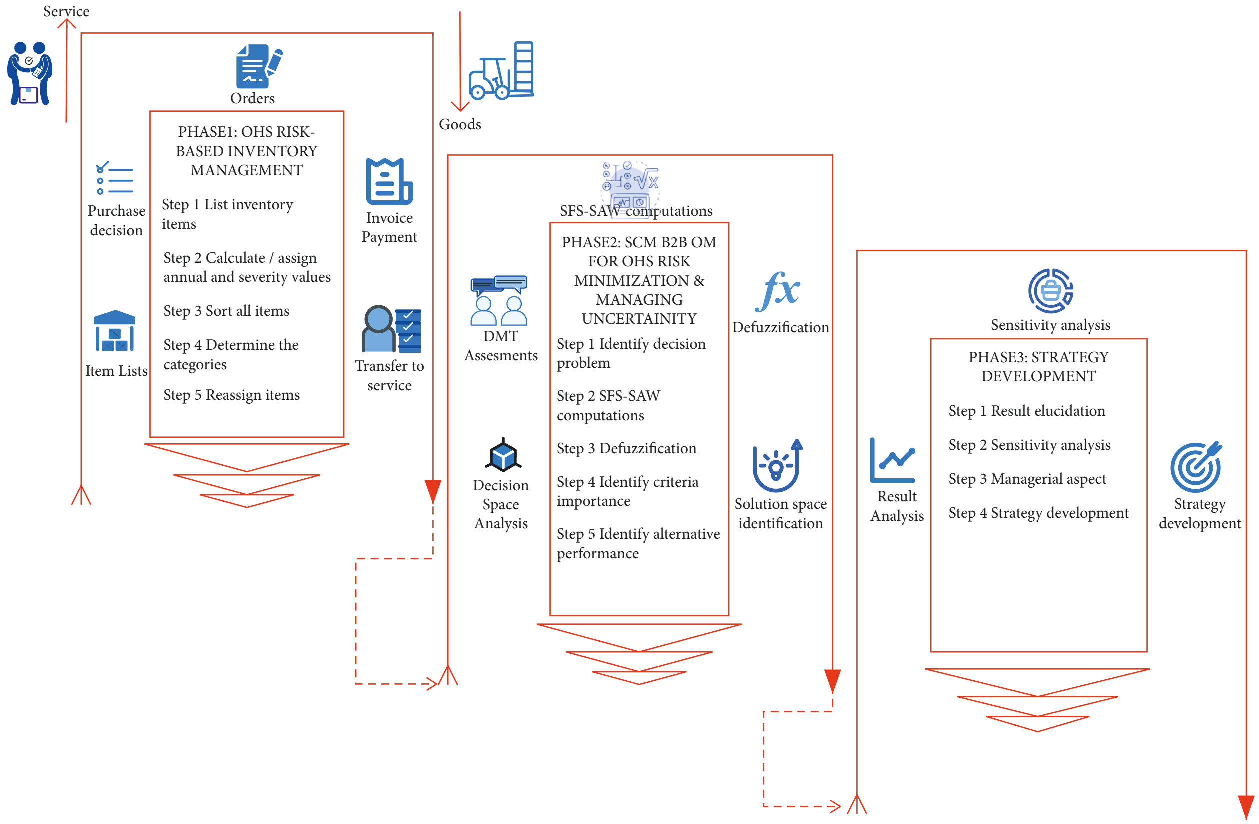

Figure 2: The proposed approach to minimize OHS risks.

$\widetilde{w}_k$: the normalized spherical fuzzy weighted importance of criteria k

$\widetilde{a}_{kj}$: the linguistic performance value of supplier j on criteria k

T_{tf}: the scenario t pertain to calculation run f.

3.2.3. Decision Variables

x_{ij}: if the inventory item i purchased from supplier j is equal to 1, otherwise 0

w_k: the overall defuzzified importance of criteria k

a_j: the defuzzified performance score of supplier j.

3.3. ABC Analysis. The ABC inventory control method was developed by the General Electric Company in the 1950s to help inventory management by categorization of the products, components, or raw materials to be purchased.

The following steps are followed in ABC analysis implementation to categorize goods for inventory control problems [17].

Step 1. All inventory items should be listed.

Step 2. The expected demand of all listed inventory items should be determined in units and the unit price by the employment of Equation (1).

$$\text{Annual investment value}_\text{i} = \frac{\text{Unit price}_{ij}}{\text{Cost}_{ij}} * \text{Annual demand}_\text{i}. \tag{1}$$

Step 3. All inventory items should be sorted by total annual investment values from the highest to the lowest one.

Step 4. The percentages of units for each item to the total units of all items and the total value of each item to the total value of all items should be calculated.

Step 5. The cumulative sums of the percentages found in Step 4 should be calculated.

Step 6. All inventoried items should be categorized according to the cumulative percentages found in Step 5.

The roots of the ABC analysis method go back to "Pareto's rule" of "Vital few and trivial many" based on the capital investment of the item which was proposed to related literature in 1896 by Italian economist Vilfredo Pareto [17]. This method provides a simple check for close control to separate entity types that do not require control from the essential ones by dividing inventoried goods into three separate groups: (i) *Category A* goods make up only 10% of the total quantity, while having 70% in sales value; (ii) *Category B* goods in the middle are 20% of the total amount with 20% and 15–20% share in sales value, and at the other extreme; (iii) *Category C* goods have only as little as 5% to 10% of sales value as 60% to 70% when producing total quantity [29]. Here, *Category A* needs the tightest control, *Category C* requires minimal attention, and *Category B* deserves less attention than *Category A* but more than *Category C*.

3.4. VED Analysis. VED (vital essential desirable) analysis is a technique for classifying inventories according to their functional importance or health-related supremacy.

VED analysis classifies the inventory items into three categories as vital (*V*), required (*E*), and desirable (*D*). Here, *Category V* includes critical goods for the health of employees and minimization of OHS risks, *Category E* represents inventory materials with lower critical importance than *Category V*, where inventory materials with the lowest severity to cause any OHS risks should be listed under *Category D* [18].

There is no denying that stocking particular items can be expensive and tie up a lot of capital and that bringing efficiencies to such important cost drivers—often 30–40% of the budget—can present meaningful savings [16]. On the other hand, the limitation of ABC analysis is that it is based only on monetary values and the cost of consumption of items; however, some items of low monetary value would be lifesaving or vital for human health. The importance of items belonging to this group should not be overlooked simply because they were not listed in *Category A* with the ABC method. On that occasion, an additional parameter of assessment according to the criticality levels of inventoried items for human health could be performed by VED analysis [21].

3.5. Spherical Fuzzy Sets. The concept of SFS was proposed by Kutlu Gündoğdu and Kahraman [48] and introduced to the related literature as an extension of intuitionistic fuzzy sets by synthesizing Pythagorean and Neutrosophic fuzzy sets. The SFS calculation mechanism grounds on the assumption that the sum of the squares of the fuzzy number element belonging to a fuzzy set, nonmembership, and hesitancy degrees will be less than or equal to 1, and here membership functions of fuzzy elements can be defined independently of each other, provided that they remain within the boundaries of a sphere [48–51].

According to the SFS, where E_1 and E_2 were assumed to be two universes and $\tilde{A}_s$ and $\tilde{B}_s$ were assumed to be the universe of discourse E_1 and E_2, the following mathematical equations could be employed (equations (2)–(7)).

$$\tilde{A}_s = \left\{u, \left(\mu_{\tilde{A}_s}(u), \nu_{\tilde{A}_s}(u), \pi_{\tilde{A}_s}(u)\right) \mid u \in E_1\right\}, \tag{2}$$

$$\tilde{B}_s = \left\{r, \left(\mu_{\tilde{B}_s}(r), \nu_{\tilde{B}_s}(r), \pi_{\tilde{B}_s}(r)\right) \mid r \in E_2\right\}, \tag{3}$$

$$\begin{aligned}\mu_{\tilde{A}_s}(u)\colon E_1 \longrightarrow [0,1], \nu_{\tilde{A}_s}(u)\colon E_1 \\ \longrightarrow [0,1], \pi_{\tilde{A}_s}(u)\colon E_1 \longrightarrow [0,1],\end{aligned} \tag{4}$$

$$\begin{aligned}\mu_{\tilde{B}_s}(r)\colon E_2 \longrightarrow [0,1], \nu_{\tilde{B}_s}(r)\colon E_2 \\ \longrightarrow [0,1], \pi_{\tilde{B}_s}(r)\colon E_2 \longrightarrow [0,1],\end{aligned} \tag{5}$$

$$0 \leq \mu^2\tilde{A}_s(u) + \nu^2\tilde{A}_s(u) + \pi^2\tilde{A}_s(u) \leq 1, \ \forall u \in E_1, \tag{6}$$

$$0 \leq \mu^2\tilde{B}_s(r) + \nu^2\tilde{B}_s(r) + \pi^2\tilde{B}_s(r) \leq 1, \ \forall r \in E_2. \tag{7}$$

Here, for each x and y, the membership function, the nonmembership function, and the hesitancy degree of element x and element y were represented $\mu\tilde{A}_s(u)$, $\nu\tilde{A}_s(u)$, and $\pi\tilde{A}_s(u)$, and $\mu\tilde{B}_s(r)$, $\nu\tilde{B}_s(r)$, and $\pi\tilde{B}_s(r)$, respectively [52].

The summation and multiplication of spherical fuzzy numbers and multiplication by scalar arithmetical operations were developed by Kutlu Gündoğdu and Kahraman [48], and are seen as follows:

$$\tilde{A}_s \oplus \tilde{B}_s = \left\{\left(\mu^2_{\tilde{B}_s} + \mu^2_{\tilde{B}_s} - \mu^2_{\tilde{A}_s}\mu^2_{\tilde{B}_s}\right)^{1/2}, \nu_{\tilde{A}_s}\nu_{\tilde{B}_s}, \left(\left(1 - \mu^2_{\tilde{B}_s}\right)\pi^2_{\tilde{A}_s} + \left(1 - \mu^2_{\tilde{A}_s}\right)\pi^2_{\tilde{B}_s} - \pi^2_{\tilde{A}_s}\pi^2_{\tilde{B}_s}\right)^{1/2}\right\}, \tag{8}$$

$$\tilde{A} \otimes \tilde{B}_s = \left\{\mu_{\tilde{A}_s}\mu_{\tilde{B}_s}, \left(\nu^2_{\tilde{A}_s} + \nu^2_{\tilde{B}_s} - \nu^2_{\tilde{A}_s}\nu^2_{\tilde{B}_s}\right)^{1/2}, \left(\left(1 - \nu^2_{\tilde{B}_s}\right)\pi^2_{\tilde{A}_s} + \left(1 - \nu^2_{\tilde{A}_s}\right)\pi^2_{\tilde{B}_s} - \pi^2_{\tilde{A}_s}\pi^2_{\tilde{B}_s}\right)^{1/2}\right\}, \tag{9}$$

$$k * \tilde{A}_s = \left\{\left(1 - \left(1 - \mu^2_{\tilde{A}_s}\right)^k\right)^{1/2}, \nu^k_{\tilde{A}_s}, \left(\left(1 - \mu^2_{\tilde{A}_s}\right)^k - \left(1 - \mu^2_{\tilde{A}_s} - \pi^2_{\tilde{A}_s}\right)^k\right)^{1/2}\right\}. \tag{10}$$

Kutlu Gündoğdu and Kahraman [48] also developed SFS operators for spherical weighted arithmetical mean (SWAM) and spherical weighted geometric mean (SWGM) operations to be used in group decision-making processes with the below seen mathematical equations (equations (11)-(12)).

$$\mathrm{SWAM}_{w}\left(\widetilde{A_{s1}}, \ldots.., \widetilde{A_{sn}}\right) = w_{1}\widetilde{A_{s1}} + w_{2}\widetilde{A_{s2}} + \ldots.. + wn\widetilde{A_{sn}} = \left\{ \begin{array}{l} \left[1 - \prod_{\mathbf{k}=1}^{\mathbf{n}} \left(1 - \boldsymbol{\mu}^{2}_{\tilde{A}_{sk}}\right)^{\mathbf{w_k}}\right]^{1/2}, \\ \prod_{\mathbf{k}=1}^{\mathbf{n}} \mathbf{v}^{\mathbf{w_k}}_{\tilde{A}_{sk}}, \left[\prod_{\mathbf{k}=1}^{\mathbf{n}} \left(1 - \boldsymbol{\mu}^{2}_{\tilde{A}_{sk}}\right)^{\mathbf{w_k}} - \prod_{\mathbf{k}=1}^{\mathbf{n}} \left(1 - \boldsymbol{\mu}^{2}_{\tilde{A}_{sk}} - \boldsymbol{\pi}^{2}_{\tilde{A}_{sk}}\right)^{\mathbf{w_k}}\right]^{1/2}, \end{array} \right. \tag{11}$$

$$\mathrm{SWGM}w\left(\widetilde{A_{s1}}, \ldots.., \widetilde{A_{sn}}\right) = w1\widetilde{A_{s1}} + w2\widetilde{A_{s2}} + \ldots.. + wn\widetilde{A_{sn}} = \left\{ \prod_{\mathbf{k}=1}^{\mathbf{n}} \boldsymbol{\mu}^{\mathbf{w_k}}_{\tilde{A}_{sk}}, \left[1 - \prod_{\mathbf{k}=1}^{\mathbf{n}} \left(1 - \mathbf{v}^{2}_{\tilde{A}_{sk}}\right)^{\mathbf{w_k}}\right]^{1/2}, \left[\prod_{\mathbf{k}=1}^{\mathbf{n}} \left(1 - \mathbf{v}^{2}_{\tilde{A}_{sk}}\right)^{\mathbf{w_k}} - \prod_{\mathbf{k}=1}^{\mathbf{n}} \left(1 - \mathbf{v}^{2}_{\tilde{A}_{sk}} - \boldsymbol{\pi}^{2}_{\tilde{A}_{sk}}\right)^{\mathbf{w_k}}\right]^{1/2}. \tag{12}$$

Here, $w = (w_1, w_2, \ldots, w_n)$; $w_k, \in [0, 1]$; $\sum_{k=1}^{n} w_k = 1$.

Although it could be considered as a relatively newly developed fuzzy set concept, SFS has quickly gained a place in the related literature and has been used with various MCDM techniques. As instances of some valuable papers employed SFS, interested readers can benefit from the studies of Ashraf and Abdullah [49], Ashraf et al. [50], Kutlu Gündoğdu and Kahraman [48], Kutlu Gündoğdu and Kahraman [51], Kutlu Gündoğdu and Kahraman [53], Mathew et al. [52], Kutlu Gündogdu and Kahraman [54], Özceylan et al. [55], and Sharaf [56] (Table 2)

3.6. Proposed Approach

Stage 1. Inventory control operations aiming OHS risk minimization

Step 1.1. All inventory items should be listed.

Step 1.2. Annual inventory values and severity values should be calculated and assigned regarding each inventory item separately, by the employment of equation (1) and experience knowledge of DMs, respectively.

Step 1.3. All inventory items should be sorted from highest to the lowest regarding both listed values, respectively.

Step 1.4. Categories of *A*, *B*, and *C* and categories of *V*, *E*, and *D* should be determined according to the results of Step 1.3.

Step 1.5. All inventory items should be reassigned into three categories such as Category I, Category II, and Category III, according to the results of Step 1.4, and the assignment rules proposed by Gupta et al.[6]. Here, as Category I, all vital (V) inventory materials and all high-investment (*A*) inventory materials should be represented to be able to handle the components and products with the highest severity levels and investment volumes, including the subclasses of AV, BV, CV, AE, and AD. Second, among the remaining inventory materials, all items listed as essential (*E*) and midinvestment (*B*) should be grouped under Category II, including the subclasses of BE, BD, and CE, where all desirable (*D*) and low-investment (C) items should be grouped under Category III, including CD subclass. The categorization employed in integrated ABC-VED analysis implementations was presented hereinafter, in Table 2.

Stage 2. SFS-SAW implementation

Step 2.1. The decision problem and elements influencing the decision environment should be defined.

Step 2.2. Evaluation matrices should be constituted for SFS-SAW computations with the use of linguistic terms.

Step 2.3. Linguistic terms in SFS-SAW evaluation matrices should be transformed into spherical numbers with the employment of identified linguistic assessment scale.

Step 2.4. Aggregated SFS-SAW evaluation matrices ($\tilde{a}$ kj: $(C_j(\tilde{a_k})_{mxn})$) should be constructed with the employment of equation (11) or equation (12) on the SFS-SAW matrices of Step 2.3.

Step 2.5. Different DM assessments should be aggregated with the SWGM operator introduced in equation (12), in the case of group decision-making processes.

Step 2.6. Spherical fuzzy criteria scores $S(\widetilde{w}_k)$) and normalized spherical fuzzy criteria weighting values $(\widetilde{w}_k)$ should be computed with the employment of equations (13)-(14), respectively.

$$S(\widetilde{w}_k) = \left(\frac{3\mu_k - \pi_k}{2}\right)^2 - \left(\frac{\nu_k - \pi_k}{2}\right)^2, \tag{13}$$

$$\widetilde{w}_k = \frac{S(\widetilde{w}_k)}{\sum_{k=1}^{n} S(\widetilde{w}_k)}. \tag{14}$$

Step 2.7. Spherical fuzzy values of alternative overall performances on the determined criteria set should be computed by the employment of the results of Step 2.6 and aggregated decision matrix, as introduced in equation (15).

$$\widetilde{A}k = \sum_{j=1}^{n} \widetilde{w}_j \widetilde{a}_{kj} \forall k. \tag{15}$$

Step 2.8. Final scores of alternatives (a_j) should be computed as introduced in equation (16), and, the alternative with the highest a_j score should be

Table 2: Categorization in integrated ABC-VED analysis.

Categories	*V*	*E*	*D*
A	AV	AE	AD
B	BV	BE	BD
C	CV	CE	CD

Table 3: DMs profiles.

Expertise field	Gender	Age	Title	Background	Experience
Purchasing and B2B relations	Male	45	Purchasing manager	Business Administration (B.Sc.)	25
OHS	Female	37	Job safety expert	Industrial Engineering (M.Sc.)	12
Purchasing and B2B relations	Male	42	Purchasing expert	Business Administration (B.Sc.)	21

identified as the one having the best performance on the determined criteria set.

$$Aj = \text{Score}\left(\widetilde{A_j}\right) = \left(\frac{3\mu_{\widetilde{A_i}} - \pi_{\widetilde{A_i}}}{2}\right)^2 - \left(\frac{\nu_{\widetilde{A_i}} - \pi_{\widetilde{A_i}}}{2}\right)^2. \qquad (16)$$

Stage 3. Further analysis and elicitation of results.

Step 3.1. The obtained results and modifications regarding criteria importance levels according to identified item groups and preference levels related to alternatives according to the OHS risk minimization objective should be furtherly analyzed.
Step 3.2. Sensitivity analysis should be performed in terms of developed scenarios reflecting varying dominion relations of diverse problem space perspectives.
Step 3.3. Strategies for differing planning periods should be developed and managerial insights and practical implications related to these should be delineated.

4. Results and Discussion

The oldest and the second largest gas distribution company in Turkey was analyzed as the case study, which serves more than 2 million subscribers in the Capital, Ankara, with a population of 5 million. This energy company has a license valid until 2037, it serves approximately 7% of the total population of Turkey in only the Capital.

The company carries out its B2B relations in cooperation with suppliers based on trust, to ensure that they perform quality production and services to their customers, while, complying with rigidly restricted OHS rules. Out of 270 different items to be purchased and 197 to be inventoried, 103 items were determined as potentially causing OHS risks for employees and having potential adverse impact on customers' health.

The group decision making method was employed in this research; a decision making team consisting of three DMs who have proven their expertise in their fields was constituted to participate in assessments. Information and demographics of DMs who took part in decision problem solution are presented to the reader (see Table 3). In this application, all DMs were accepted as having same influence on B2B decisions, which also means that there is no superiority of any DMs to another one.

4.1. Integrated ABC-VED Analysis Results. The developed integrated ABC-VED inventory control method was implemented as it was proposed by Gupta et al. [17]. The results of both ABC analysis and VED analysis, furthermore, the categorization of all 103 inventoried items having influence on OHS risks and employee/customer health verdict to integrated ABC-VED analysis are combined presented (see Table 4). The overall results are summarized for the convenience of readers in Table 5.

As it is indicated in Tables 4 and 5, not all 103 items out of 197 inventoried products and components were categorized as having the highest priority in terms of OHS risks, besides they were preliminarily listed as essential to human health. The distribution of integrated overall categories (Category I, Category II, and Category III), ABC categories, and VED categories are presented. Figure 3 is presented to scrutinize the distribution and assignment of inventoried essential items regarding the Stage 1 results.

According to the results, items assigned in Category I, which must be considered carefully in the highest criticality level, correspond to 50.48% of the total materials and 61% of the total material value. Items listed in the Category II correspond to 43.69% of the total materials and 27% of the total value. Hence, it is proved by the results that items in Category II areless important than those listed in Category I in terms of both amount and value.

The least important items categorized in Category III correspond to 0.06% of the total materials and 12% of the total value. According to Stage 1 results regarding inventory control problem aiming minimization of OHS risks, 51 out of 103 items were identified as the most critical items with the employment of integrated ABC-VED analysis.

4.2. Integrated SFS-SAW Analysis Results and Discussion. As Stage 2, analysis for B2B relationship management to minimize OHS risks was performed grounding on the results of integrated ABC-VED results by the employment of the SFS-SAW MCDM method regarding the supplier companies of relating varying products and components. 51 items assigned into categories according to their influence on OHS risks (represented with VED results) and overall market

Table 4: Stage 1 calculations.

Items	Percentage values	Cumulative values	ABC categories	VED categories	Overall categories
Rotary. G40 Dn50 150 1/160 Pmax 19,3	0.16906	0.16906	*A*	*E*	Category I
Diaphragm meter G25 Dn50	0.13199	0.30106	*A*	*E*	Category I
Diaphragm meter G10 Dn40	0.10337	0.40443	*A*	*E*	Category I
Rotary. G400 Dn150 1501/160 Pmax19,3	0.09343	0.49786	*A*	*V*	Category I
Diaphragm meter G16 Dn40	0.09154	0.58940	*A*	*V*	Category I
Rotary. G100 Dn80 150 1/160 Pmax 19,3	0.07123	0.66063	*A*	*E*	Category I
Rotary. G650 Dn150 150 1/200 P19,3 Hf	0.04747	0.70810	*B*	*V*	Category I
Rotary. G65 Dn50 150 1/160 Pmax 19, 3	0.04263	0.75072	*B*	*E*	Category II
Rotary. G250 Dn100 150 1/160 Pmax19, 3	0.02990	0.78063	*B*	*V*	Category I
Saddle 3-way sphere type 12″ × 12″	0.02540	0.80602	*B*	*D*	Category II
Saddle 3-way sphere type 8″ × 8″	0.02028	0.82630	*B*	*D*	Category II
Rotary. G160 Dn80 150 1/160 Pmax 19, 3	0.01764	0.84394	*B*	*E*	Category II
Saddle 3-way saddle type 8″ × 4″	0.01127	0.85521	*B*	*E*	Category II
Saddle 3-way collar type 12″ × 4″	0.01094	0.86615	*B*	*V*	Category I
Dıaphragm meter G6 Dn25	0.00959	0.87575	*B*	*E*	Category II
Regulator 75 m3/H 2–4 Bar/21 mbar	0.00858	0.88432	*B*	*V*	Category I
Saddle 3-way saddle type 8″ × 6″	0.00840	0.89273	*B*	*E*	Category II
Saddle 3-way saddle type 6″ × 6″	0.00796	0.90069	*C*	*E*	Category II
Saddle 3-way sphere type 6″ × 6″	0.00794	0.90863	*C*	*D*	Category III
Regulator 100 m3/H 2–4 Bar/300 mbar	0.00707	0.91570	*C*	*V*	Category I
Saddle 3-way *N* type 12″ × 2″	0.00683	0.92253	*C*	*E*	Category II
Saddle 3-way sphere type 6″ × 4″	0.00636	0.92889	*C*	*D*	Category III
Saddle 3-way collar type 16″ × 4″	0.00629	0.93519	*C*	*V*	Category I
Saddle 3-way saddle type 4″ × 4″	0.00595	0.94114	*C*	*E*	Category II
Saddle 3-way *N* type 8″ × 2″	0.00592	0.94706	*C*	*E*	Category II
Saddle 3-way saddle type 12″ × 8″	0.00580	0.95287	*C*	*E*	Category II
Saddle 3-way *N* type 6″ × 2″	0.00449	0.95735	*C*	*E*	Category II
Saddle 3-way *N* type 16″ × 2″	0.00384	0.96119	*C*	*E*	Category II
Blind flange 3″ Pn16	0.00349	0.96468	*C*	*E*	Category II
Saddle 3-way sphere type 8″ × 4″	0.00343	0.96811	*C*	*D*	Category III
Regulator 50 m3/H 2–4 Bar/300 mbar	0.00287	0.97098	*C*	*V*	Category I
Elbow ST 45° 12″ WPB 9.53 mm	0.00278	0.97376	*C*	*E*	Category II
Elbow ST 90° 12″ WPB 9.53 Mm	0.00213	0.97589	*C*	*V*	Category I
Bellow ST Gear 2″	0.00152	0.97741	*C*	*E*	Category II
Elbow ST 45° 6″ WPB 7.11 Mm	0.00126	0.97867	*C*	*E*	Category II
Elbow ST 22.50° 12″ WPB 9.53 Mm	0.00121	0.97988	*C*	*V*	Category I
Regulator 25 m3/H 2–4 Bar/21 mbar 180°	0.00115	0.98103	*C*	*V*	Category I
Flange neck 4″ Ansı300	0.00111	0.98214	*C*	*V*	Category I
Regulator100 m3/H 2–4 Bar/21 mbar	0.00105	0.98320	*C*	*V*	Category I
KEP ST 12″ WPB 9.53 Mm	0.00092	0.98412	*C*	*V*	Category I
Elbow ST 90° 16″ WPB 9.53 Mm	0.00091	0.98503	*C*	*E*	Category II
Motherboard	0.00089	0.98592	*C*	*E*	Category II
KEP ST 24″ WPHY52 9.53 Mm	0.00082	0.98674	*C*	*V*	Category I
Elbow ST 22.50° 16″ WPB 9.53 Mm	0.00079	0.98753	*C*	*V*	Category I
Blind flange 6″ Pn16	0.00073	0.98826	*C*	*E*	Category II
Metallic flexible block-rear cabinet combined kit	0.00072	0.98898	*C*	*E*	Category II
TEE Inegal 12″ × 4″ WPB 9.53 × 6.02 Mm	0.00071	0.98970	*C*	*V*	Category I
KEP ST 16″ WPB 9.53 mm	0.00063	0.99033	*C*	*V*	Category I
TEE Inegal 12″ × 8″ Wpb 9.53 × 8.18 Mm	0.00063	0.99096	*C*	*V*	Category I
Regulator 75 m3/H 2–4 Bar/21 mbar 180°	0.00057	0.99153	*C*	*V*	Category I
Weldolet 8′—2′ 3000 lb	0.00045	0.99198	*C*	*V*	Category II
Gas Suction Pump	0.00039	0.99237	*C*	*E*	Category II
Reduction ST 16″ × 12″ WPB 9.53 × 9.53 Mm	0.00038	0.99275	*C*	*V*	Category I
CO Sensor	0.00037	0.99312	*C*	*E*	Category II
Lel/Gas Sensor	0.00036	0.99349	*C*	*E*	Category II
TEE Inegal 12″ × 6″ WPB 9.53 × 7.11 Mm	0.00036	0.99384	*C*	*V*	Category I
Elbow ST 11.25 12″ WPB 9.53 Mm	0.00034	0.99418	*C*	*V*	Category I
Blind Flange 10″ Class600	0.00032	0.99450	*C*	*E*	Category II
TEE Inegal 6″ × 4″ WPB 7.11 × 6.02 Mm	0.00031	0.99481	*C*	*V*	Category I

Table 4: Continued.

Items	Percentage values	Cumulative values	ABC categories	VED categories	Overall categories
Weldolet 12′—2′ 3000 lb	0.00031	0.99513	*C*	*V*	Category I
Flange Neck 16″ Pn16	0.00027	0.99540	*C*	*V*	Category I
Motherboard Psu Unıt	0.00026	0.99566	*C*	*E*	Category II
TEE Inegal 8″ × 4″ WPB 8.18 × 6.02 Mm	0.00025	0.99591	*C*	*V*	Category I
Flange Neck 6″ Pn16	0.00022	0.99613	*C*	*V*	Category I
LCD Screen	0.00022	0.99635	*C*	*E*	Category II
Regulator 50 m3/H 2–4 Bar/21 mbar 180°	0.00022	0.99657	*C*	*V*	Category I
KEP ST 8″ WPB 8.18 Mm	0.00021	0.99678	*C*	*V*	Category I
Stainless steel open-end 35 cm Probe for high Temperature gas controls	0.00019	0.99697	*C*	*E*	Category II
Blind Flange 12″ Pn16	0.00018	0.99715	*C*	*E*	Category II
KEP ST 6″ WPB 7.11 Mm	0.00017	0.99731	*C*	*V*	Category I
Blind flange 423 Cls300	0.00016	0.99748	*C*	*E*	Category II
Closed ended side hole 35 cm plastic probe for ground gas leak detection	0.00015	0.99763	*C*	*E*	Category II
Blind flange 6″ Cls150	0.00015	0.99777	*C*	*E*	Category II
Front cabin block	0.00014	0.99792	*C*	*E*	Category II
Weldolet 24’—2’ 3000lb	0.00014	0.99805	*C*	*V*	Category I
TEE equal 6″ WPB 7.11 Mm	0.00013	0.99819	*C*	*V*	Category I
KEP ST 4″ WPB 6.02 Mm	0.00013	0.99832	*C*	*V*	Category I
Weldolet 18′—2′ 3000 lb	0.00012	0.99844	*C*	*V*	Category I
Carbon filter material 1 kg	0.00012	0.99856	*C*	*E*	Category II
PPM sensor	0.00011	0.99867	*C*	*E*	Category II
Reduction 12″ × 8″ WPB 12.7 × 12.7 Mm	0.00009	0.99876	*C*	*V*	Category I
Blind Flange 2″ Ansı300	0.00009	0.99885	*C*	*E*	Category II
ELBOW ST 45° 4″ WPB 6.02 Mm	0.00009	0.99893	*C*	*E*	Category II
Blind Flange 8″ Pn16	0.00008	0.99902	*C*	*E*	Category II
ELBOWST 90° 6″ WPB 7.11 Mm	0.00008	0.99909	*C*	*V*	Category I
Calibratıon	0.00008	0.99917	*C*	*E*	Category II
Weldolet 16′—2′ 3000 lb	0.00007	0.99925	*C*	*V*	Category I
Blind Flange 2″ Ansı 150	0.00007	0.99932	*C*	*E*	Category II
Maintenance-repair cost	0.00007	0.99938	*C*	*D*	Category III
Silica filter/carbon filter block	0.00006	0.99944	*C*	*E*	Category II
Battery block cover	0.00006	0.99951	*C*	*E*	Category II
Weldolet 6′—½′ 3000 lb	0.00006	0.99957	*C*	*V*	Category I
Weldolet 12′—½′ 3000 lb	0.00006	0.99963	*C*	*V*	Category I
Flange neck 2″ 300	0.00006	0.99969	*C*	*V*	Category I
Weldolet 8′—½′ 3000 lb	0.00006	0.99975	*C*	*V*	Category I
Protection Sheath	0.00006	0.99980	*C*	*D*	Category III
Weldolet 4′—½′ 3000 lb	0.00005	0.99985	*C*	*V*	Category I
Silica gel filter material 1 kg	0.00004	0.99990	*C*	*E*	Category II
Flange flat open 8″ Cls150	0.00003	0.99992	*C*	*V*	Category I
Weldolet 6′—2′ 3000 lb	0.00003	0.99995	*C*	*V*	Category I
Powder Pack 30	0.00002	0.99997	*C*	*D*	Category III
Hydrophobic filter-1 piece	0.00002	0.99999	*C*	*E*	Category II
Flange slip-on 4″ Ansı150	0.00001	1.00000	*C*	*V*	Category I

structure (represented with ABC results) were analyzed under six headings, since the supplier companies of the items could be grouped for item subsets (see Table 5). Item groups obtained in terms of the supplier companies and related investment values for each item group are presented in Table 6, where the list of all inventoried items according to the related item groups is also presented to the readers in Table7.

Since having the responsibility to present continuous service with high quality standards as being the leader energy company in gas distribution market obstructs the existing challenges in OHS risk minimization and B2B relations, the company asserts several prerequisites to their possible suppliers, which narrows down the alternatives set. There are two possible supplier companies regarding the purchase of the items listed under the Calibration and Maintenance group (SU, ESA), where three and four supplier companies could be able to be considered for items under Saddles, and Regulators and Components groups (PR, TD, GIO; ES, GA, FI), and meter I and meter II groups (NA, KA, MA, EL; NA, ME, MA, EL), respectively. The number of certified suppliers for items grouped under Steel Fittings is again three possible

Table 5: Integrated ABC-VED results.

Categories	Count	Cost (TL)	%	
			Cost	Count
I (AV + AE + AD + BV + CV)	51	4673565.36	0.61	0.50
II (BE + CE + BD)	46	2077409.89	0.27	0.44
III (CD)	6	933500.96	0.12	0.06
Total	103	7684476.21	1.00	1.00

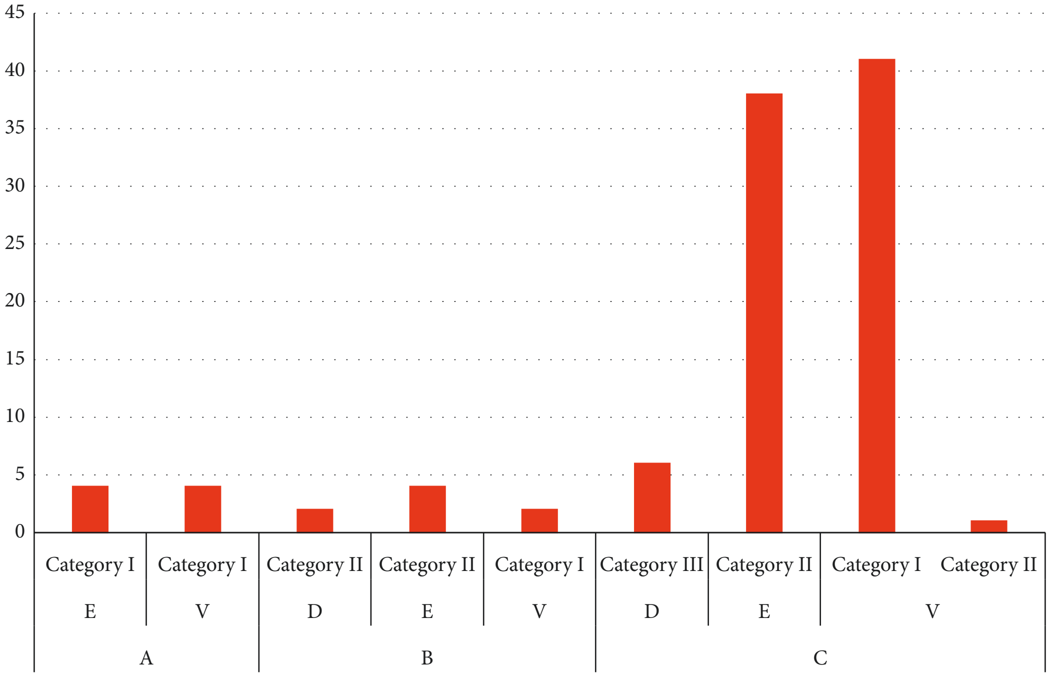

Figure 3: Distribution of inventoried item into categories.

Table 6: Category I item groups according to supplier companies.

Item groups	Costs (TL)
Calibration and maintenance	33315
Meter I	2585782
Meter II	3622200
Saddles	1084407
Regulators and components	165302
Steel fittings	193469
Total	7684476

supplier companies (SAY, MAN, MET). Company names of the suppliers are given in abbreviations due to secrecy policies of the organization. Since the alternative supplier companies vary according to the identified item groups, Stage 2 substeps of the proposed approach was implemented in six rounds for each item group separately, from Step 2.1 to Step 2.8, respectively. The SWGM operator introduced in (12) was employed to create aggregated SFS-SAW evaluation matrices.

The criteria set was created in the light of the performed delineated literature review [57–68] and the field knowledge of DMs. Dickson [69] conducted one of the first and most comprehensive studies on supplier selection problem through a questionnaire research applied to 273 randomly selected purchasing experts and executives from the National Association of Purchasing, USA. 23 criteria were identified in results, with the most important ones being product quality, on-time delivery, and warranty policy [69]. Price, Lead time, Damaged/delinquent delivery, Reliability, Warranty terms, and Trade volume criteria were determined to be considered as the decision criteria for the handled B2B relationship management problem according to the employment frequency of each criterion in the related literature and the insights and opinions of DMs according to their field experience. 1–9 Likert type linguistic term scale was employed to reflect DMs' judgements into the results at best (see Table 8). The evaluation matrices regarding alternative organization performances on the identified criteria set are presented in Table 9 for each DM and item group separately, where the $S(\widetilde{w}_j)$, $\overline{w}_j$, and final criteria weight values, and $\widetilde{A}_{ji}$, a_{ji}, and final alternative scores are presented in Tables 10 and 11, respectively, for each item group.

As Tables 10 and 11 indicated both criteria weights and performances of even same companies on the identified criteria set were varying according to corresponding item groups. The ESA, KA, EL, TD, and ES supplier companies were selected to perform best related to B2B relationship achievement levels in terms of OHS risk minimization target grounding on the criteria set includes six identified criteria "Cost," "Lead time," "Damaged/delinquent delivery,"

Table 7: Category I items under identified item groups.

Item groups	Inventoried items
Calibration and maintenance	BATTERY BLOCK COVER
Steel fittings	BELLOW ST GEAR 2″
Steel fittings	BLIND FLANGE 3″ PN16
Steel fittings	BLIND FLANGE 4″ CLS300
Steel fittings	BLIND FLANGE 10″ CLASS600
Steel fittings	BLIND FLANGE 12″ PN16
Steel fittings	BLIND FLANGE 2″ ANSI 150
Steel fittings	BLIND FLANGE 2″ ANSI300
Steel fittings	BLIND FLANGE 6″ Cls150
Steel fittings	BLIND FLANGE 6″ PN16
Steel fittings	BLIND FLANGE 8″ PN16
Calibration and maintenance	CALIBRATION
Calibration and maintenance	CARBON FILTER MATERIAL 1 kg
Calibration and maintenance	CLOSED ENDED SIDE HOLE 35 cm PLASTIC PROBE FOR GROUND GAS LEAK DETECTION
Calibration and maintenance	CO SENSOR
Meter I	DIAPHRAGM METER G10 DN40
Meter I	DIAPHRAGM METER G16 DN40
Meter I	DIAPHRAGM METER G25 DN50
Meter I	DIAPHRAGM METER G6 DN25
Steel fittings	ELBOW ST 11.25°12″ WPB 9.53 mm
Steel fittings	ELBOW ST 22.50° 12″ WPB 9.53 mm
Steel fittings	ELBOW ST 22.50° 16″ WPB 9.53 mm
Steel fittings	ELBOW ST 45° 12″ WPB 9.53 mm
Steel fittings	ELBOW ST 45° 4″ WPB 6.02 mm
Steel fittings	ELBOW ST 45° 6″ WPB 7.11 mm
Steel fittings	ELBOW ST 90° 16″ WPB 9.53 mm
Steel fittings	ELBOWST 90° 12″ WPB 9.53 mm
Steel fittings	ELBOWST 90° 6″ WPB 7.11 mm
Steel fittings	FLANGE FLAT OPEN 8″ CLS150
Steel fittings	FLANGE Neck 2″ ANSI300
Steel fittings	FLANGE Neck 4″ ANSI300
Steel fittings	Flange neck 16″ PN16
Steel fittings	Flange neck 6″ PN16
Steel fittings	Flange slip-ON 4″ ANSI150
Calibration and maintenance	Front cabin block
Calibration and maintenance	Gas suction pump
Calibration and maintenance	Hydrophobic filter-1 piece
Steel fittings	KEP ST 12″ WPB 9.53 mm
Steel fittings	KEP ST 16″ WPB 9.53 mm
Steel fittings	KEP ST 24″ WPHY52 9.53 mm
Steel fittings	KEP ST 4″ WPB 6.02 mm
Steel fittings	KEP ST 6″ WPB 7.11 mm
Steel fittings	KEP ST 8″ WPB 8.18 mm
Calibration and maintenance	LCD screen
Calibration and maintenance	LEL/gas sensor
Calibration and maintenance	Maintenance-repair cost
Calibration and maintenance	Metallic flexible block and rear cabinet combined kit
Calibration and maintenance	Motherboard
Calibration and maintenance	Motherboard PSU unit
Calibration and maintenance	Powder pack 30
Calibration and maintenance	PPM sensor
Calibration and maintenance	Protection sheath
Steel fittings	Reduction 12″ × 8″ WPB 12.7 × 12.7 mm
Steel fittings	Reduction ST 16″ × 12″ WPB 9.53 × 9.53 mm
Regulators and components	Regulator 100 m3/h 2–4 bar/300 mbar
Regulators and components	REGULATOR 25 m3/h 2–4 bar/21 mbar 180°
Regulators and components	REGULATOR 50 m3/h 2–4 bar/21 mbar 180°
Regulators and components	REGULATOR 75 m3/h 2–4 bar/21 mbar 180°
Regulators and components	REGULATOR100 m3/h 2–4 bar/21 mbar

Table 7: Continued.

Item groups	Inventoried items
Regulators and components	REGULATOR50 m3/h 2–4 bar/300 mbar
Regulators and components	REGULATOR75 m3/h 2–4 bar/21 mbar
Meter II	Rotary. G40 DN50ANSI150 1/160 Pmax 19, 3
Meter II	Rotary. G100 DN80ANSI150 1/160 Pmax 19, 3
Meter II	Rotary. G160 DN80ANSI150 1/160 Pmax 19, 3
Meter II	Rotary. G250 DN100ANSI150 1/160 Pmax19, 3
Meter II	Rotary. G400 DN150ANSI1501/160 Pmax19, 3
Meter II	Rotary. G65 DN50ANSI150 1/160 Pmax 19, 3
Meter II	Rotary. G650 DN150ANSI150 1/200 P19, 3 HF
Saddles	SADDLE 3-WAY COLLAR TYPE 12″ × 4″
Saddles	SADDLE 3-WAY COLLAR TYPE 16″ × 4″
Saddles	SADDLE 3-WAY N TYPE 12″ × 2″
Saddles	SADDLE 3-WAY N TYPE 16″ × 2″
Saddles	SADDLE 3-WAY N TYPE 6″ × 2″
Saddles	SADDLE 3-WAY N TYPE 8″ × 2″
Saddles	SADDLE 3-WAY SADDLE TYPE 4″ × 4″
Saddles	SADDLE 3-WAY SADDLE TYPE 6″ × 6″
Saddles	SADDLE 3-WAY SADDLE TYPE 8″ × 4″
Saddles	SADDLE 3-WAY SADDLE TYPE 8″ × 6″
Saddles	SADDLE 3-WAY SADDLE TYPEP 12″ × 8″
Saddles	SADDLE 3-WAY SPHERE TYPE 12″ × 12″
Saddles	SADDLE 3-WAY SPHERE TYPE 8″ × 4″
Saddles	SADDLE 3-WAY SPHERE TYPE 8″ × 8″
Saddles	SADDLE 3-WAY SPHERE TYPE 6″ × 4″
Saddles	SADDLE 3-WAY SPHERE TYPE 6″ × 6″
Calibration and maintenance	SILICA FILTER/CARBON FILTER BLOCK
Calibration and maintenance	SILICA GEL FILTER MATERIAL 1 kg
Calibration and maintenance	STAINLESS STEEL OPEN-END 35 cm PROBE FOR HIGH TEMPERATURE GAS CONTROLS
Steel fittings	TEE EQUAL 6″ WPB 7.11 mm
Steel fittings	TEE INEGAL 12″ × 6″ WPB 9.53 × 7.11 mm
Steel fittings	TEE INEGAL 12″ × 8″ WPB 9.53 × 8.18 MM
Steel fittings	TEE INEGAL 6″ × 4″ WPB 7.11 × 6.02 mm
Steel fittings	TEE INEGAL 8″ × 4″ WPB 8.18 × 6.02 mm
Steel fittings	TEE INEGAL 12″ × 4″ WPB 9.53 × 6.02 mm
Steel fittings	WELDOLET 12′—½′ 3000LB
Steel fittings	WELDOLET 12′—2′ 3000LB
Steel fittings	WELDOLET 16′—2′ 3000LB
Steel fittings	WELDOLET 18′—2′ 3000LB
Steel fittings	WELDOLET 24′—2′ 3000LB
Steel fittings	WELDOLET 4′—½′ 3000LB
Steel fittings	WELDOLET 6′—½′ 3000LB
Steel fittings	WELDOLET 6′—2′ 3000LB
Steel fittings	WELDOLET 8′—½′ 3000LB
Steel fittings	WELDOLET 8′—2′ 3000LB

Table 8: Linguistic terms and corresponding SFNs.

Linguistic terms	SFNs
Absolutely more important (AMI)	(0.9, 0.1, 0.1)
Very high important (VHI)	(0.8, 0.2, 0.2)
High important (HI)	(0.7, 0.3, 0.3)
Slightly more important (SMI)	(0.6, 0.4, 0.4)
Equally important (EI)	(0.5, 0.5, 0.5)
Slightly low important (SLI)	(0.4, 0.6, 0.4)
Low important (LI)	(0.3, 0.7, 0.3)
Very low important (VLI)	(0.2, 0.8, 0.2)
Absolutely low important (ALI)	(0.1, 0.9, 0.1)

"Reliability," "Warranty terms," and "Trade volume" regarding the first four item groups determined in terms of the supplier companies of the included inventoried items. The supplier ES was found to be the best in B2B relationship management regarding the fifth- and sixth-item groups.

Some additional examinations were made on the research results as further analysis of the outcomes. The modification of criteria weights according to item groups is visualized in Figure 4, where difference between the alternative supplier companies are investigated furtherly with Figure 5.

According to SFS-SAW computation outcomes grounding on integrated ABC-VED implementation results, "Damaged/delinquent delivery" criterion was found to have

Table 9: SFS-SAW evaluation matrices corresponding to supplier data and DM assessments.

			DM1			
			Criteria			
			Calibration and maintenance			
Alternatives	COST	LEAD TIME	DDD	RELIABILITY	WARRANTY TERMS	TRADE VOLUME
SU	LI	LI	VHI	LI	HI	HI
ESA	EI	EI	HI	VHI	SMI	HI
Meter I						
NA	SMI	LI	SLI	VHI	VHI	HI
KA	EI	EI	LI	HI	HI	SMI
MA	EI	LI	EI	SMI	HI	EI
EL	SLI	SLI	SLI	VHI	VHI	EI
Meter II						
NA	SLI	SMI	EI	SMI	HI	SMI
KA	EI	SMI	HI	HI	SMI	SMI
MA	HI	SLI	SMI	SMI	HI	VHI
EL	SMI	SMI	SLI	HI	HI	HI
Saddles						
PR	HI	HI	SLI	SMI	HI	VHI
TD	SLI	AMI	HI	SMI	HI	AMI
GIO	AMI	SLI	SLI	VHI	VHI	HI
Regulator and parts						
ES	SMI	HI	SLI	HI	SMI	SMI
GA	SLI	HI	HI	SLI	SMI	HI
FI	VHI	EI	SMI	EI	SMI	SMI
Steel fittings						
SAY	HI	HI	SMI	HI	SMI	VHI
MAN	SMI	EI	HI	VHI	SMI	VHI
MET	SLI	HI	HI	VHI	SMI	SMI
DM2						
SU	LI	LI	SMI	VHI	SMI	VHI
ESA	HI	HI	SLI	SMI	LI	VHI
Meter I						
NA	HI	SMI	HI	SMI	SMI	HI
KA	EI	VHI	EI	HI	HI	HI
MA	EI	SLI	EI	VHI	HI	VHI
EL	SLI	SMI	SLI	HI	VHI	VHI
Meter II						
NA	LI	SMI	SMI	EI	HI	SMI
KA	SLI	SMI	HI	VHI	HI	EI
MA	HI	SLI	EI	SMI	SMI	HI
EL	EI	SMI	SLI	HI	HI	VHI
Saddles						
PR	VHI	EI	EI	SMI	HI	VHI
TD	EI	HI	SMI	EI	SMI	VHI
GIO	AMI	LI	LI	HI	VHI	EI
Regulator and parts						
ES	EI	SMI	EI	HI	HI	SMI
GA	LI	SMI	VHI	EI	SMI	HI
FI	HI	LI	SMI	SMI	EI	HI
Steel fittings						
SAY	VHI	SMI	HI	HI	EI	HI
MAN	SMI	LI	SMI	SMI	SMI	HI
MET	SLI	SMI	VHI	AMI	SMI	EI
DM3						
SU	LI	VLI	EI	HI	VHI	EI
ESA	VHI	HI	VHI	EI	EI	EI
Meter I						
NA	VHI	EI	SMI	SLI	HI	HI

Table 9: Continued.

DM1						
Criteria						
Calibration and maintenance						
Alternatives	COST	LEAD TIME	DDD	RELIABILITY	WARRANTY TERMS	TRADE VOLUME
KA	SMI	HI	HI	EI	SMI	VHI
MA	EI	SLI	HI	HI	VHI	VHI
EL	SLI	EI	EI	HI	HI	LI
Meter II						
NA	SLI	SMI	EI	SMI	HI	HI
KA	EI	SMI	SMI	HI	HI	EI
MA	HI	LI	HI	SMI	SMI	HI
EL	SMI	SMI	SLI	VHI	HI	VHI
Saddles						
PR	SMI	SMI	LI	HI	HI	HI
TD	VLI	VHI	SMI	SMI	HI	VHI
GIO	VHI	VLI	LI	AMI	VHI	SMI
Regulator and parts						
ES	SLI	SMI	SMI	VHI	SMI	HI
GA	VLI	HI	VHI	SLI	EI	HI
FI	SMI	EI	HI	EI	EI	SMI
Steel fittings						
SAY	HI	EI	VHI	AMI	EI	HI
MAN	EI	VLI	HI	EI	EI	VHI
MET	LI	EI	SMI	VHI	EI	SMI
DMs						
DM1	VHI	VHI	VHI	HI	HI	EI
DM2	SMI	HI	VHI	VHI	HI	SLI
DM3	VHI	HI	HI	HI	SLI	LI
Meter I						
DM1	VHI	HI	SMI	EI	SMI	HI
DM2	VHI	HI	SMI	SMI	SMI	VHI
DM3	HI	HI	EI	EI	SMI	VHI
Meter II						
DM1	AMI	HI	HI	SMI	HI	SMI
DM2	VHI	HI	HI	SMI	VHI	HI
DM3	AMI	SMI	EI	HI	HI	VHI
Saddles						
DM1	HI	VHI	VHI	SMI	SMI	SMI
DM2	HI	HI	HI	HI	SMI	VHI
DM3	VHI	VHI	HI	VHI	SMI	HI
Regulator and parts						
DM1	SMI	EI	SMI	HI	HI	VHI
DM2	EI	SMI	SMI	VHI	HI	VHI
DM3	EI	SMI	SMI	HI	VHI	AMI
Steel fittings						
DM1	AMI	VHI	HI	HI	LI	SMI
DM2	VHI	HI	SMI	SMI	LI	SMI
DM3	AMI	AMI	SMI	SMI	EI	HI

the highest importance ($w_k = 0.231$) in B2B relationship management regarding OHS risks minimization for corresponding item group "Calibration and Maintenance." The most vital criteria corresponding to differing inventoried item groups were indicated as diversifying as well; "Cost" criterion was identified as the most important for item groups Meter II and Steel Fittings ($w_k = 0.272$; $w_k = 0.307$); similarly, "Trade volume" criterion was identified as the most important criteria for item groups Meter I and Regulator and Parts ($w_k = 0.240$; $w_k = 0.280$), respectively. Furthermore, "Lead time" ($w_k = 0.205$) criterion was determined as having the biggest impact in terms of the item group Saddles. As the results indicate, due to the complexity and vagueness included in the decision problem structure, while it was revealed that the results obtained vary in a wide range for each examined item group, the final weight scores of the criteria on the basis of groups are very close to each other in some cases (see Table 10 and Figure 4). This

Table 10: $S\ (\tilde{w}_k)$, $\overline{w}_k$ and final criteria weight results corresponding varying item groups.

	Cost	Lead time	DDD	Reliability	Warranty terms	Trade volume
Calibration & maintenance						
$S(\tilde{w}_k)$	4.116	4.222	4.719	4.222	2.387	0.780
$\overline{w}_k$	0.201	0.207	0.231	0.207	0.117	0.038
Meter I						
$S(\tilde{w}_k)$	4.719	3.780	2.123	1.787	2.520	4.719
$\overline{w}_k$	0.239	0.192	0.108	0.091	0.128	0.240
Meter II						
$S(\tilde{w}_k)$	6.370	3.302	2.783	2.885	4.222	3.687
$\overline{w}_k$	0.274	0.142	0.120	0.124	0.182	0.159
Saddles						
$S(\tilde{w}_k)$	4.222	4.719	4.222	3.687	2.520	3.687
$\overline{w}_k$	0.183	0.205	0.183	0.160	0.109	0.160
Regulator and parts						
$S(\tilde{w}_k)$	1.787	2.123	2.520	4.222	4.222	5.796
$\overline{w}_k$	0.086	0.103	0.122	0.204	0.204	0.280
Steel fittings						
$S(\tilde{w}_k)$	6.370	5.175	2.885	2.885	0.565	2.885
$\overline{w}_k$	0.307	0.249	0.139	0.139	0.027	0.139
Criteria rank						
Calibration and maintenance	3	2	1	2	4	5
Meter I	2	3	5	6	4	1
Meter II	1	4	6	5	2	3
Saddles	2	1	2	3	5	4
Regulator & parts	5	4	3	2	2	1
Steel fittings	1	2	3	4	5	3

Table 11: $\widetilde{A}_j$, a_j, and final alternative score results corresponding varying item groups.

			Rank				
Calibration and maintenance				Saddles			
SU	(0.228, 0.894, 0.164)	−0.297	2	PR	(0.915, 0.178, 0.170)	7.068	2
ESA	(0.313, 0.860, 0.201)	0.125	1	TD	(0.915, 0.185, 0.166)	7.070	1
Meter I				GIO	(0.900, 0.219, 0.150)	6.86375	3
NA	(0.289, 0.849, 0.180)	0.029	4	Regulator and parts			
KA	(0.339, 0.854, 0.205)	0.270	1	ES	(0.956, 0.127, 0.131)	7.856	1
MA	(0.335, 0.865, 0.206)	0.233	2	GA	(0.948, 0.151, 0.125)	7.734	3
EL	(0.320, 0.880, 0.184)	0.135	3	FI	(0.952, 0.137, 0.144)	7.747	2
Meter II				Steel fittings			
NA	(0.252, 0.872, 0.196)	5.902	4	ES	(0.325, 0.822, 0.180)	0.249	1
KA	(0.338, 0.859, 0.206)	6.214	2	GA	(0.289, 0.868, 0.192)	−0.004	3
MA	(0.350, 0.846, 0.184)	6.181	3	FI	(0.301, 0.860, 0.187)	0.065	2
EL	(0.361, 0.843, 0.189)	6.334	1				

occasion also underlined the accuracy and propriety of the decision to employ SFS linguistic terms and mathematical operation functions in computations to reflect the human judgement and vagueness in the benchmarking process and to investigate the multicriteria variable structure of the addressed problem with a group decision making approach which enables scientific researchers to include judgements and experience of more than one DM particularly in this kind of multidimensional complex problems.

4.3. Sensitivity Analysis.

A series of sensitivity analysis experiments were carried out to survey the performance of the proposed approach and analyze the influence of differing perspectives on the solution space structure. Six different scenarios were developed in these aims including the main application scenario, where, two of the new scenarios represent the existence of contentious situations, two represent the existence of a dominant DM perspective, and one represents the existence of two different dominant DM perspectives. Comprehensive information about the developed scenarios were presented in details, hereinafter.

T_{11}: Equal dominance levels for all DMs (w_{D1}: 0.333; w_{D2}: 0.333; w_{D3}: 0.333) (*main application case*)

T_{21}: Contentious situation-I (w_{D1}: 0.6; w_{D2}: 0.1; w_{D3}: 0.3)

T_{22}: Contentious situation-I (w_{D1}: 0.1; w_{D2}: 0.3; w_{D3}: 0.6)

T_{23}: Contentious situation-I (w_{D1}: 0.3; w_{D2}: 0.6; w_{D3}: 0.1)

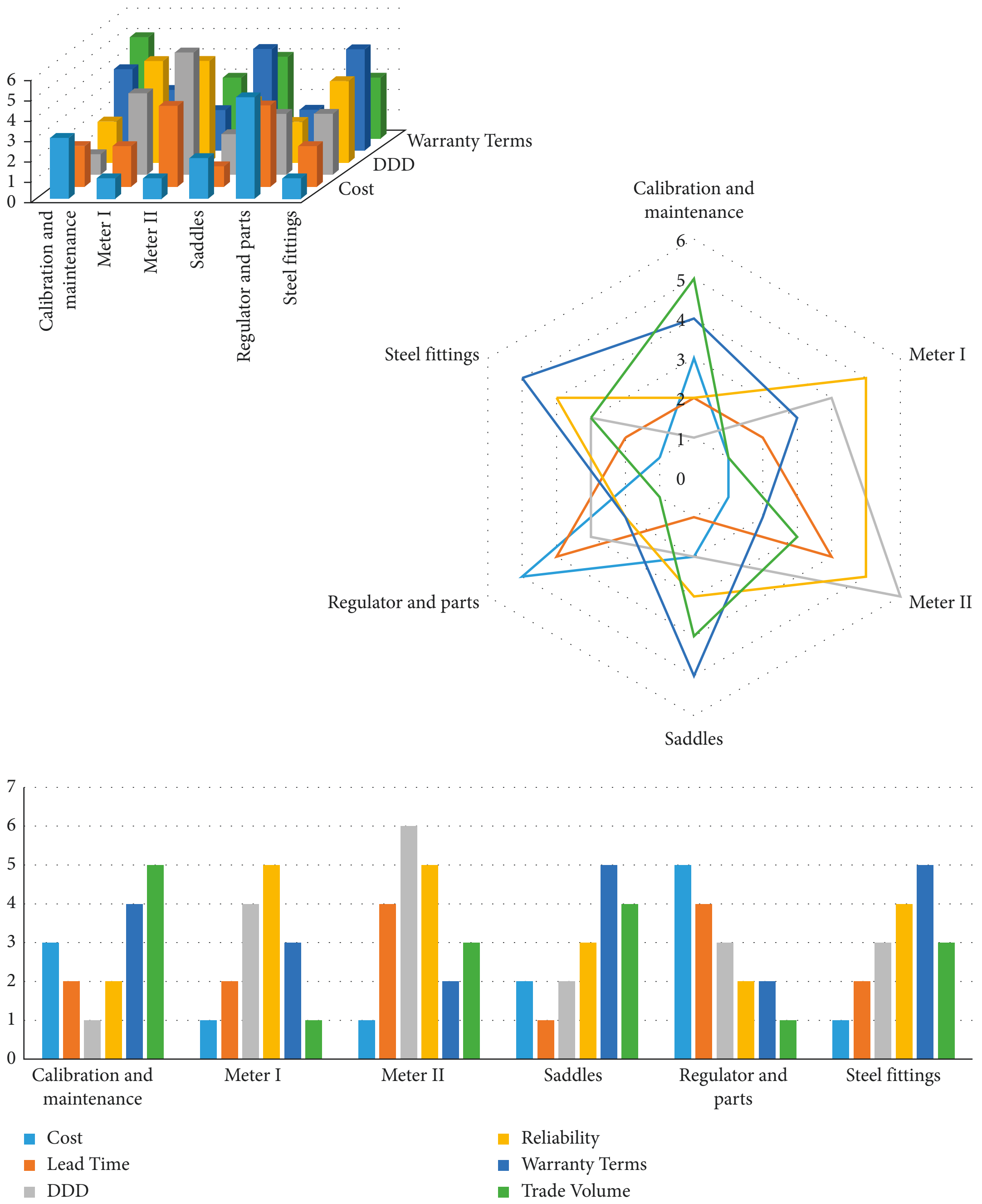

Figure 4: Influence of decision criteria according to different item groups.

T_{31}: Contentious situation-II (w_{D1}: 0.5; w_{D2}: 0.3; w_{D3}: 0.2)

T_{32}: Contentious situation-II (w_{D1}: 0.2; w_{D2}: 0.5; w_{D3}: 0.3)

T_{33}: Contentious situation-II (w_{D1}: 0.3; w_{D2}: 0.2; w_{D3}: 0.5)

T_{41}: Existence of a dominant DM-I (w_{D1}: 0.7; w_{D2}: 0.1; w_{D3}: 0.2)

T_{42}: Existence of a dominant DM-I (w_{D1}: 0.2; w_{D2}: 0.1; w_{D3}: 0.7)

T_{43}: Existence of a dominant DM-I (w_{D1}: 0.1; w_{D2}: 0.2; w_{D3}: 0.7)

T_{51}: Existence of a dominant DM-II (w_{D1}: 0.8; w_{D2}: 0.1; w_{D3}: 0.1)

T_{52}: Existence of a dominant DM-II (w_{D1}: 0.1; w_{D2}: 0.1; w_{D3}: 0.8)

T_{53}: Existence of a dominant DM-II (w_{D1}: 0.1; w_{D2}: 0.8; w_{D3}: 0.1)

T_{61}: Existence of two dominant DMs (w_{D1}: 0.4; w_{D2}: 0.4; w_{D3}: 0.2)

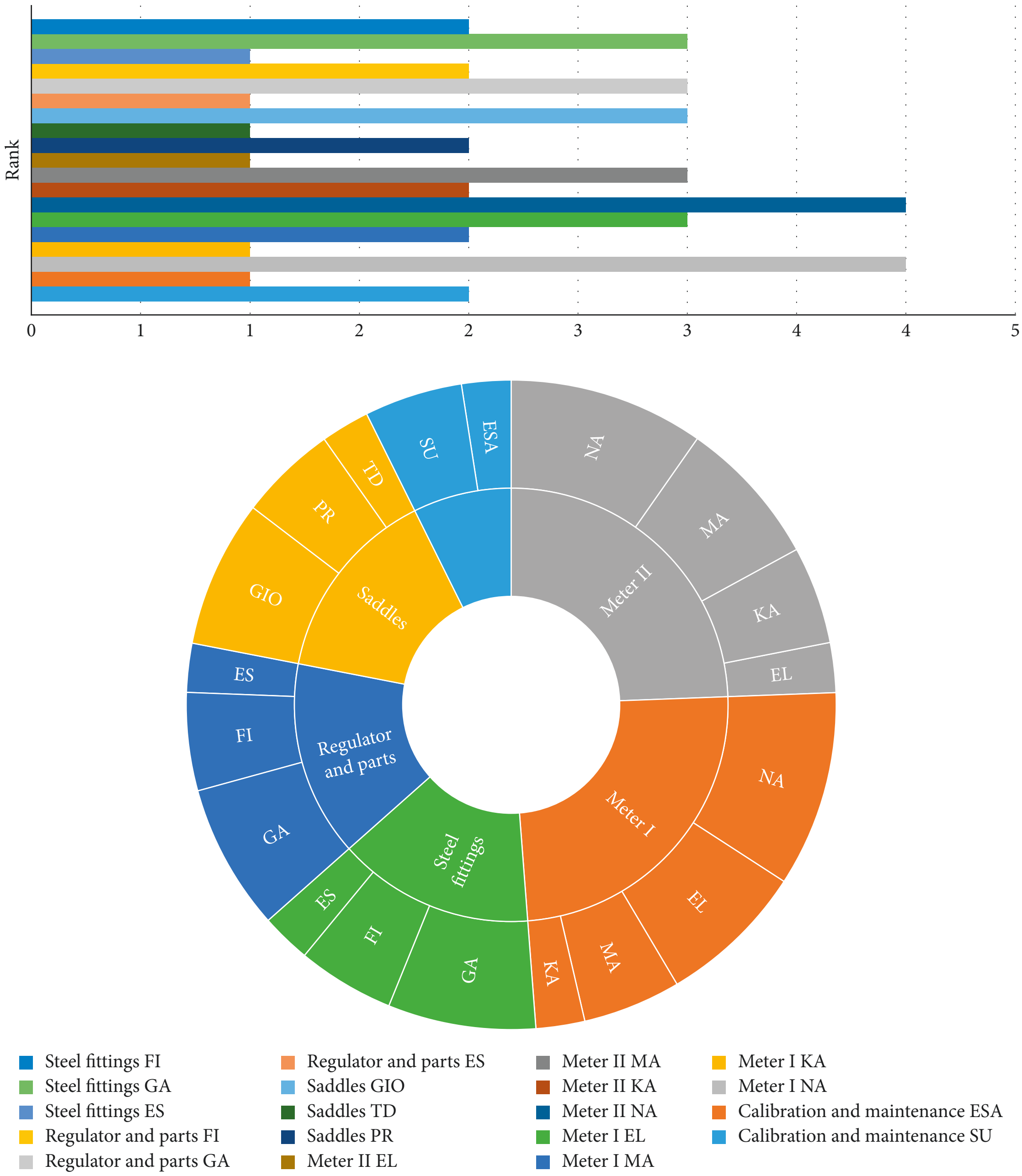

Figure 5: Modification on preference of alternatives according to different item groups.

T_{62}: Existence of two dominant DMs (w_{D1}: 0.4; w_{D2}: 0.2; w_{D3}: 0.4)

T_{63}: Existence of two dominant DMs (w_{D1}: 0.2; w_{D2}: 0.4; w_{D3}: 0.4)

In order to examine these six scenarios developed for the sensitivity analysis application, 15 additional calculation runs (T_{tf}, t: 1, ..., 6; f: 1, ..., 3) were performed for six alternative OHS risks related inventory items purchased from varying suppliers (x_{ij}, i: 1, ..., 6; j: 1, ..., 4) through three DM perspectives (D_d, d: 1, 2, 3). Acquired solution results are epitomized in Tables 12–14 and Figure 6.

Tables 12 and 13 summarize the variation on the final alternative scores, and Figure 6 illustrates the variation on overall criteria weight results schematized upon the data presented in Table 14 according to the diverse dominance levels of differing DM perspectives, respectively. As a result of the sensitivity analysis experiments performed through the scenarios created depending on the different impact values assigned to several DM perspectives, changed alternative priority orders are indicated in bold in Table 13.

As Tables 12 and 13 indicated, the superiority degree of the alternatives represented with a_j values almost does not change depending on the modifications experienced on the DM assessments importance, or, weighting scores. Likewise, it is seen that the importance scores of the decision criteria represented by w_k values, that is, their power to influence the decision process are also not influenced by the modifications

Table 12: Variance of final alternative score a_j results.

	a_j values															
	T_{11}	T_{21}	T_{22}	T_{23}	T_{31}	T_{32}	T_{33}	T_{41}	T_{42}	T_{43}	T_{51}	T_{52}	T_{53}	T_{61}	T_{62}	T_{63}
Calibration and maintenance																
SU	−0.30	−0.31	−0.29	−0.22	−0.28	−0.25	−0.33	−0.27	−0.19	−0.31	−0.23	−0.34	−0.14	−0.27	−0.33	−0.28
ESA	0.13	0.20	0.20	0.06	0.13	0.09	0.18	0.21	0.04	0.25	0.22	0.32	0.03	0.10	0.17	0.12
Meter I																
NA	0.03	0.00	0.09	0.03	0.00	0.05	0.04	−0.01	0.05	0.10	−0.01	0.11	0.08	0.01	0.02	0.06
KA	0.27	0.19	0.38	0.28	0.22	0.32	0.29	0.16	0.32	0.39	0.15	0.41	0.37	0.25	0.25	0.32
MA	0.23	0.14	0.40	0.21	0.15	0.29	0.28	0.10	0.26	0.42	0.07	0.44	0.32	0.19	0.22	0.31
EL	0.13	0.11	0.08	0.24	0.16	0.17	0.09	0.13	0.27	0.05	0.15	0.03	0.31	0.17	0.10	0.13
Meter II																
NA	−0.17	−0.17	−0.14	−0.17	−0.18	−0.17	−0.16	−0.18	−0.17	−0.13	−0.19	−0.12	−0.16	−0.17	−0.16	−0.16
KA	0.26	0.23	0.26	0.30	0.25	0.29	0.24	0.23	0.32	0.25	0.23	0.24	0.34	0.27	0.24	0.27
MA	0.35	0.40	0.33	0.32	0.37	0.33	0.36	0.40	0.31	0.34	0.41	0.35	0.29	0.35	0.37	0.33
EL	0.42	0.39	0.50	0.39	0.38	0.43	0.45	0.36	0.40	0.52	0.34	0.54	0.42	0.39	0.42	0.45
Saddles																
PR	0.05	0.04	0.02	0.11	0.06	0.07	0.02	0.06	0.13	0.01	0.07	0.00	0.15	0.07	0.03	0.05
TD	0.46	0.62	0.38	0.43	0.53	0.39	0.47	0.67	0.39	0.39	0.72	0.41	0.35	0.48	0.51	0.40
GIO	0.53	0.56	0.53	0.52	0.54	0.51	0.54	0.57	0.50	0.55	0.58	0.59	0.49	0.53	0.54	0.52
Regulator and parts																
ES	0.02	−0.01	0.07	0.00	−0.01	0.03	0.04	−0.02	0.01	0.08	−0.03	0.09	0.02	0.00	0.02	0.04
GA	0.27	0.25	0.27	0.28	0.26	0.27	0.26	0.25	0.28	0.27	0.26	0.26	0.29	0.27	0.26	0.27
FI	0.15	0.18	0.12	0.16	0.17	0.14	0.14	0.20	0.16	0.12	0.22	0.12	0.15	0.16	0.15	0.13
Steel fittings																
ES	0.25	0.24	0.25	0.28	0.25	0.26	0.24	0.24	0.29	0.24	0.25	0.24	0.30	0.26	0.24	0.25
GA	0.00	0.06	−0.05	0.00	0.04	−0.03	−0.01	0.09	−0.02	−0.05	0.14	−0.05	−0.04	0.02	0.01	−0.03
FI	0.07	0.07	0.00	0.15	0.10	0.08	0.02	0.09	0.16	−0.03	0.12	−0.05	0.17	0.11	0.04	0.05

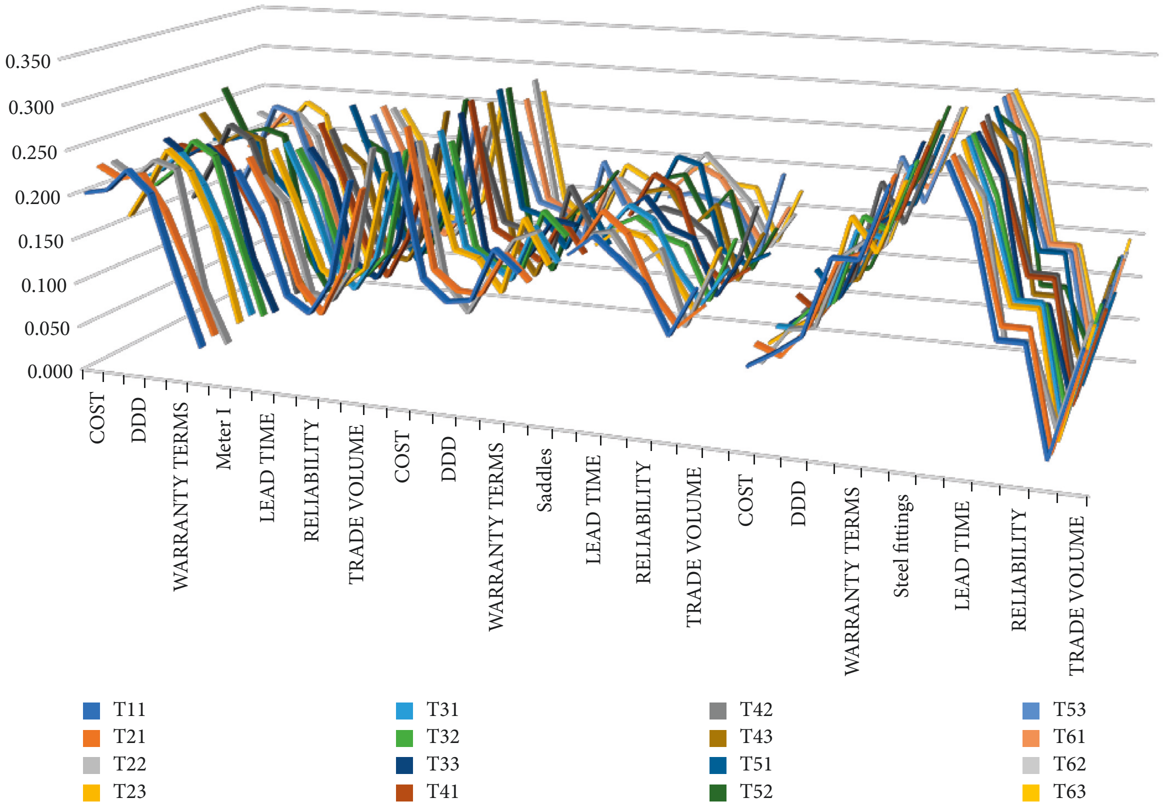

Figure 6: Variance of criteria weights according to w_k values in terms of developed scenarios.

Table 13: Variance of final ranks of alternatives.

	Ranks															
	T_{11}	T_{21}	T_{22}	T_{23}	T_{31}	T_{32}	T_{33}	T_{41}	T_{42}	T_{43}	T_{51}	T_{52}	T_{53}	T_{61}	T_{62}	T_{63}
Calibration and maintenance																
SU	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
ESA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Meter I																
NA	4	4	3	4	4	4	4	4	4	3	4	3	4	4	4	4
KA	1	1	2	1	1	1	1	1	1	2	2	2	1	1	1	1
MA	2	2	1	3	3	2	2	3	3	1	3	1	2	2	2	2
EL	3	3	4	2	2	3	3	2	2	4	1	4	3	3	3	3
Meter II																
NA	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
KA	3	3	3	3	3	3	3	3	2	3	3	3	2	3	3	3
MA	2	1	2	2	2	2	2	1	3	2	1	2	3	2	2	2
EL	1	2	1	1	1	1	1	2	1	1	2	1	1	1	1	1
Saddles																
PR	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
TD	2	1	2	2	2	2	2	1	2	2	1	2	2	2	2	2
GIO	1	2	1	1	1	1	1	2	1	1	2	1	1	1	1	1
Regulator and parts																
ES	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
GA	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
FI	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Steel fittings																
ES	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
GA	3	3	3	3	3	3	3	2	3	3	2	2	3	3	3	3
FI	2	2	2	2	2	2	2	3	2	2	3	3	2	2	2	2

in DM assessment importance levels, which are used in reflecting the DMs' judgements into the SFS-SAW calculations (Figure 6).

The results of 15 additive computation runs within six different application scenarios showed that both alternative priorities and criteria importance scores are insensitive to the change in the power of different DM perspectives to influence the computation outcomes has proven that the proposed approach can yield robust, effective, and reliable results by removing the effects of human judgement on the decision making process.

4.4. Managerial Insights and Practical Implications. The purpose of all OHS activities is to protect employees, to ensure production safety and to ensure operational safety. OHS is of great importance in order to follow a regular and prudent pathway in OM implications. The obligation of employers in this regard is to take all measures for OHS risk elimination or minimization and to prevent accidents.

OHS risk minimization activities, which are often associated and carried out with efforts and activities in tactical dimensions, should also be associated with activities carried out on a more strategic basis from a macro perspective. In this way, a broader approach to OHS risk minimization can be developed, where, accidents which could occur in any workplace might be eliminated even before their root-causes were emerged.

This study suggests the employment of a robust novel approach specifically developed for OHS risk minimization to articulate the OHS standpoint with SCM operations through inventory management and B2B relationship management. The proposed approach uses the integrated ABC-VED method to simultaneously consider the severity, cost, and amount parameters of purchased items, where suppliers were also investigated on their performances in terms of OHS risks and basic SCM criteria. Risk assessment procedures bring uncertainty and vagueness to the problem spaces to which they relate by their very nature, where both OHS risk assessment procedures and supplier selection problem require DM insights and assessments as input data. The proposed approach introduced SFS based SAW solution methodology to handle this mentioned uncertainty; correspondingly, the results of the performed case study from energy industries approved the robustness and reliability of the proposed approach.

As indicated with the results, field executives and scientific researchers could depend on the proposed approach with greater peace of mind, where sensitivity analysis results indicated that neither alternative performance scores nor criteria dominance sequence varied in response to the modifications on the weightings of DMs, which means influence levels of DM perspectives on final results. In these regards, this novel approach could be adapted and effectively implemented in many different application fields without being limited to only energy industry, or B2B relationship management activities of SCM practices.

The criteria set identified in this study could be a valuable resource for field practitioners and scientific researchers on energy, petroleum, and, maintenance and repair companies

Table 14: Calculated w_k values for each item group in sensitivity analysis.

	w_j values															
	$T11$	$T21$	$T22$	$T23$	$T31$	$T32$	$T33$	$T41$	$T42$	$T43$	$T51$	$T52$	$T53$	$T61$	$T62$	$T63$
Calibration and maintenance																
Cost	0.201	0.226	0.225	0.157	0.195	0.181	0.230	0.218	0.148	0.246	0.209	0.267	0.139	0.184	0.222	0.199
Lead time	0.207	0.213	0.209	0.194	0.206	0.200	0.211	0.212	0.190	0.211	0.211	0.213	0.186	0.203	0.211	0.205
Ddd	0.231	0.220	0.230	0.237	0.228	0.237	0.226	0.220	0.240	0.226	0.218	0.220	0.243	0.232	0.226	0.234
Reliability	0.207	0.181	0.223	0.215	0.193	0.221	0.205	0.174	0.225	0.218	0.167	0.213	0.235	0.203	0.198	0.219
Warranty terms	0.117	0.116	0.086	0.153	0.133	0.124	0.095	0.128	0.155	0.075	0.141	0.065	0.157	0.135	0.106	0.110
Trade volume	0.038	0.044	0.027	0.043	0.045	0.036	0.033	0.049	0.041	0.024	0.053	0.022	0.039	0.043	0.038	0.034
Meter I																
Cost	0.240	0.249	0.223	0.248	0.250	0.237	0.233	0.256	0.244	0.220	0.263	0.216	0.241	0.247	0.240	0.234
Lead time	0.192	0.198	0.196	0.183	0.192	0.188	0.197	0.196	0.181	0.199	0.195	0.202	0.179	0.189	0.196	0.191
Ddd	0.108	0.113	0.096	0.116	0.115	0.107	0.102	0.118	0.115	0.092	0.123	0.089	0.113	0.114	0.107	0.104
Reliability	0.091	0.083	0.091	0.099	0.089	0.097	0.087	0.082	0.103	0.088	0.081	0.085	0.107	0.093	0.087	0.094
Warranty terms	0.128	0.132	0.130	0.122	0.128	0.125	0.132	0.131	0.121	0.133	0.130	0.135	0.119	0.126	0.131	0.128
Trade volume	0.240	0.226	0.264	0.231	0.226	0.245	0.249	0.217	0.236	0.269	0.208	0.273	0.241	0.231	0.240	0.250
Meter II																
Cost	0.274	0.296	0.275	0.249	0.276	0.259	0.286	0.295	0.241	0.283	0.293	0.290	0.233	0.268	0.286	0.268
Lead time	0.142	0.145	0.127	0.153	0.150	0.143	0.133	0.151	0.152	0.122	0.156	0.116	0.151	0.149	0.139	0.138
Ddd	0.120	0.124	0.093	0.146	0.135	0.122	0.103	0.136	0.145	0.085	0.148	0.077	0.144	0.135	0.113	0.112
Reliability	0.124	0.123	0.137	0.111	0.117	0.121	0.133	0.118	0.110	0.143	0.113	0.148	0.110	0.117	0.128	0.127
Warranty terms	0.182	0.169	0.179	0.195	0.179	0.190	0.174	0.169	0.200	0.172	0.168	0.166	0.206	0.185	0.175	0.185
Trade volume	0.159	0.142	0.189	0.146	0.142	0.164	0.170	0.132	0.151	0.195	0.122	0.202	0.157	0.147	0.159	0.170
Saddles																
Cost	0.183	0.184	0.190	0.174	0.180	0.180	0.189	0.180	0.173	0.194	0.177	0.198	0.171	0.179	0.186	0.184
Lead time	0.205	0.224	0.197	0.192	0.212	0.193	0.209	0.228	0.184	0.201	0.231	0.205	0.177	0.204	0.213	0.197
Ddd	0.183	0.203	0.161	0.186	0.198	0.174	0.177	0.213	0.178	0.159	0.223	0.157	0.171	0.191	0.186	0.172
Reliability	0.160	0.144	0.183	0.154	0.147	0.166	0.167	0.136	0.159	0.186	0.128	0.190	0.164	0.152	0.158	0.170
Warranty terms	0.109	0.111	0.104	0.112	0.112	0.109	0.107	0.112	0.111	0.102	0.114	0.101	0.110	0.112	0.109	0.107
Trade volume	0.160	0.135	0.165	0.182	0.152	0.178	0.151	0.131	0.194	0.158	0.128	0.150	0.207	0.162	0.148	0.170
Regulator and parts																
Cost	0.086	0.101	0.073	0.086	0.096	0.080	0.084	0.108	0.081	0.073	0.115	0.072	0.076	0.091	0.089	0.079
Lead time	0.103	0.091	0.111	0.106	0.096	0.109	0.103	0.088	0.111	0.110	0.085	0.109	0.115	0.101	0.099	0.108
Ddd	0.122	0.124	0.117	0.124	0.125	0.121	0.120	0.126	0.123	0.116	0.128	0.115	0.121	0.124	0.122	0.120
Reliability	0.204	0.193	0.194	0.226	0.207	0.214	0.192	0.196	0.232	0.186	0.198	0.178	0.238	0.212	0.195	0.206
Warranty terms	0.204	0.206	0.214	0.192	0.200	0.200	0.212	0.202	0.190	0.220	0.198	0.225	0.188	0.198	0.209	0.206
Trade volume	0.280	0.284	0.290	0.266	0.276	0.276	0.289	0.280	0.264	0.296	0.276	0.301	0.261	0.274	0.286	0.281
Steel fittings																
Cost	0.307	0.307	0.300	0.311	0.309	0.307	0.303	0.309	0.311	0.298	0.310	0.295	0.311	0.309	0.306	0.305
Lead time	0.249	0.250	0.263	0.234	0.242	0.245	0.260	0.244	0.232	0.270	0.239	0.276	0.231	0.241	0.255	0.252
Ddd	0.139	0.145	0.123	0.150	0.148	0.138	0.130	0.152	0.148	0.118	0.158	0.114	0.146	0.147	0.137	0.134
Reliability	0.139	0.145	0.123	0.150	0.148	0.138	0.130	0.152	0.148	0.118	0.158	0.114	0.146	0.147	0.137	0.134
Warranty terms	0.027	0.024	0.041	0.018	0.021	0.027	0.034	0.020	0.019	0.046	0.016	0.050	0.019	0.021	0.029	0.031
Trade volume	0.139	0.128	0.150	0.138	0.131	0.144	0.141	0.124	0.142	0.151	0.119	0.151	0.146	0.135	0.137	0.145

serving organizations working on critical lines, as it was identified upon delineated literature surveys and valuable knowledge and experience of the DMs.

Furthermore, researchers and field practitioners can benefit from the SCM and OHS risk minimization aspects by concentrating on criteria that will be determined to be of high importance in their own applications during investment decisions. As other attempts, paying attention to the relationships with the suppliers having the highest performance can again be of great benefit as the eminent results of B2B analysis showed us. It should be noted here that suppliers with a cost win will not always provide the best performance in terms of OHS risk minimization.

The very fruitful results of this study are of versatility and depth that can provide benefit to experts and DMs, as well as scientific researchers, operating in the relevant field.

5. Conclusions

A novel approach for minimizing OHS risks through inventory control applications in regards with SCM OM and B2B relationship development activities was proposed in this study, with the employment of integrated ABC-VED analysis and SFS-based SAW method. A real-world case study related to the leader gas distribution company of Turkish energy sector was performed, and effectiveness, agility, and accuracy of the proposed approach was demonstrated.

The protoset of 270 different items to be purchased and 197 to be inventoried was eliminated to 103 inventoried items which corresponds with OHS risks and might cause adverse impacts on human health. Integrated ABC-VED analysis identified the most critical item group as 51 items listed in Category I in regards with OHS risk minimization target, where that subset of items was also divided into six item groups according to the supplier companies to develop B2B relationship management strategies.

Group decision-making approach and fuzzy sets were employed to handle the complexity and vagueness of the decision space. The varying criteria weights and the best-performing companies among contestants were delineated in terms of each item group; furthermore, results were interpreted separately and comparatively in terms of final ranking scores, diverging impact domains regarding different DMs' assessments as further analysis. Sensitivity analysis were also performed to evaluate the influence of different DM perspectives on the overall results and solution space structure. Subsequently, managerial strategies and suggestions for practical implications were addressed in lieu with the study outcomes. A brief summary of the performed analysis, results, and yielded benefits are listed below for convenience of the readers.

A standpoint connecting ergonomics science and OHS measures to SCM and OM activities was constructed.

(i) SFS was introduced to SCM-OM decision processes.

(ii) OHS risk minimization target was handled with inventory management activities.

(iii) Integrated ABC-VED inventory management technique was introduced to energy industries.

(iv) Criteria importance levels were identified with SFS-SAW computations to be able to handle the uncertainty of the process, grounding on OHS risk minimization main target.

(v) As results, "Damaged/delinquent delivery" ($w_k = 0.231$), "Trade volume" ($w_k = 0.240$), "Cost" ($w_k = 0.272$), "Lead time" ($w_k = 0.205$), "Trade volume" ($w_k = 0.0.280$), and "Cost" ($w_k = 0.307$) criteria were found to have the highest importance in B2B relationship management regarding OHS risks minimization for corresponding item groups "Calibration and Maintenance," "Meter I," "Meter II," "Saddles," "Regulator and Parts," and "Steel Fittings," respectively.

(vi) "ESA," "KA," "EL," "TD," and "ES" supplier companies were selected to perform best regarding the corresponding item groups in terms of OHS risk minimization target grounding on the identified decision criteria set.

(vii) Sensitivity analysis were performed with 16 computation runs (including the main case study computation) in regards of the developed six different scenarios. As consequence of these experiments, the results did not respond to changes in the input data; hence, the proposed approach has been proven to give reliable results away from influence of human judgements.

The width of DMs set identified to take part in the assessment of the research could be considered as a limitation for this study; hence, as a suggestion for future works, the DM group could be widened by considering different parties of SCM-B2B relationship structure. As another suggestion, different fuzzy sets and linguistic summarization representations could be employed to investigate the diverse influence of linguistic expression projection on the results.

The proposed approach is competent to be utilized as a base model for scientific researchers and field practitioners from differing activity fields and could easily be adjusted for possible other specific application domains in terms of their exclusive point of views or requirements. The proposed approach is also suitable to be used with different MCDM methods than SAW and easily be adapted to differentiated working environments when required [23, 40, 42–44].

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

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