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A novel spherical fuzzy AHP-VIKOR methodology to determine serving petrol station selection during COVID-19 lockdown: A pilot study for İstanbul

Ertugrul Ayyildiz [a,*], Alev Taskin [b]

[a] Department of Industrial Engineering, Karadeniz Technical University, 61080, Trabzon, Turkey
[b] Department of Industrial Engineering, Yildiz Technical University, 34349, İstanbul, Turkey

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ABSTRACT

COVID-19 pandemic has affected the entire world. During the Covid-19 pandemic, which is tried to be prevented by all countries of the world, regulations have been made to reduce the effect of the virus in sectors such as banking, tourism, and especially transportation. Social isolation is one of the most critical factors for people who have or are at risk of contracting COVID-19 disease. Many countries have developed different solutions to ensure social isolation. By applying lockdown for specific periods, preventing the movement of people will reduce the rate of transmission. However, some private and public institutions that have to serve during the lockdown period should be carefully determined. In this study, we aim to determine the petrol stations to serve during the COVID-19 lockdown, and this problem is handled as a multi-criteria decision-making problem. We extend the spherical fuzzy VlseKriterijumska Optimizacija IKompromisno Resenje (SF-VIKOR) method with the spherical fuzzy Analytic Hierarchy Process (SF-AHP). To show its applicability in complex decision-making problems, Istanbul is selected to perform a case study; thirteen petrol stations are evaluated as potential serving petrol station alternatives during the lockdown. Then, the novel SF-AHP integrated SF-VIKOR methodology is structured; the problem is solved with this methodology, and the best alternative is determined to serve in lockdown. Accessibility of the petrol station and Measures taken by station managers are determined to be essential for the effectiveness of the lockdown process. The neighborhood population and the station's proximity to hospitals are also critical inner factors to fight the pandemic. To test the methodology, Spherical Fuzzy the Weighted Aggregated Sum-Product Assessment (SF-WASPAS) is utilized. Public or private organizations can use the proposed methodology to improve their strategies and operations to prevent the spreading of COVID-19.

1. Introduction

In December 2019, the pneumonia epidemic, first seen in Wuhan city of China, due to the newly defined SARS-CoV-2 factor, is defined as Coronavirus disease 2019 (COVID-19) [1]. The epidemic spreads rapidly, and on January 26, 2020, the existence of the virus was confirmed on all continents except Antarctica [2]. The first COVID-19 case in Turkey was detected on March 11, 2020. On the same date, the World Health Organization (WHO) announced this epidemic as a pandemic [3]. According to the reports published by WHO, there are more than seven million confirmed cases and more than four hundred thousand deaths in earlier June 2020 [4]. Studies for the treatment of such a large epidemic affecting 217 countries in the world are still ongoing.

COVID-19 is transmitted from person to person very quickly by droplet [5–7]. COVID-19 can be transmitted by the secretions of infected people caused by coughing and sneezing when they contact a healthy person's hands [8]. Also, COVID-19 is smeared from contaminated dry surfaces through hands, nose, eyes, or mouth mucous membranes [9]. For this reason, methods such as social isolation, use of personal protective equipment (mask, gloves, etc.), and protection of social distance (at least 1 m) have become very important in preventing contamination [10]. When the measures taken for the rearrangement of human movements in public life areas are examined, it is seen that compulsory changes and innovations have to be made in the cities. The increased population density in cities, close contact among people, high mobility,

* Corresponding author. Department of Industrial Engineering, Karadeniz Technical University, 61080, Trabzon, Turkey.
E-mail addresses: ertugrulayyildiz@ktu.edu.tr (E. Ayyildiz), ataskin@yildiz.edu.tr (A. Taskin).

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public transportation, and common spaces are the factors that cause the spread of infection rapidly. In this context, countries have started to apply different methods to prevent the COVID-19 pandemic.

The People's Republic of China, where the outbreak first appeared, took strict lockdown and social isolation measures from the beginning and a low mortality rate occurred [11]. The pandemic spreads very rapidly in Italy due to the delay in taking restrictive and protective measures. Besides, it is understood that the pandemic is spread with insufficient equipment and experienced the process more difficult [12]. Similar situations are observed in Spain and France, with high mortality rates [13]. Sweden, the Netherlands, and the United Kingdom have tried the Herd Immunity method to fight against COVID-19 [14–16]. They gave up this method and started taking measures to suppress the pandemic after the severe situations due to the loss of control in Italy and Spain [17]. Some measures such as lockdown for risky population, closure of public places of rest and recreation to public access, not being allowed to sit in restaurants, regulation on the working hours of the markets and the number of customers shopping in the markets, etc. are taken within the scope of the fight against the pandemic in Turkey, in the first stage [18]. Later, some lockdowns are implemented to prevent the pandemic, and the first lockdown was on April 10, 2020 [19].

However, some private and public institutions have to continue their operations during the lockdown. Some of these are public and private health institutions, state agencies, and organizations required to maintain mandatory public services, strategic facilities in the energy sector, and food and cleaning materials production facilities. The transportation of employees and managers of these institutions is important to provide these services properly and operate the institutions effectively. Public transport or private vehicles can be used for transportation. The fuel needs of public transit and private vehicles can only be provided by authorized petrol stations. In this context, the determination of the petrol stations to serve during lockdown is essential. Multiple factors should be taken into account when determining which stations to serve during the lockdown. In addition, the factors related to the spread of the outbreak must be taken into consideration while meeting the need for fuel. So the process of deciding on which station(s) to serve during lockdown should involve both quantitative and qualitative criteria. This is a classical type of decision-making problem. The decision-making problems usually include more than one criteria are called multi-criteria decision-making problems. To the best of our knowledge, there is no comprehensive study in the literature about the petrol station selection problem considering the pandemic conditions.

Upchurch et al. focus on the petrol station site selection problem. A capacitated location model is presented with some constraints related to vehicles' numbers [20]. Lim and Kuby present an algorithm-based solution methodology to select the most appropriate site for a petrol station that sells alternative fuels [21]. Sun et al. present a location model of a petrol station for network expansion strategy. Set covering method is used with a greedy algorithm to determine the size and location of a new petrol station considering existing petrol stations [22]. Aslani and Alesheikh present a GIS-based solution for the location selection of petrol stations, especially small stations. They define the criteria and weighted criteria with fuzzy Analytical Hierarchy Process (AHP) methodology, and then GIS is used to determine the best alternative [23]. MirHassani and Ebrazi develop a set covering mathematical model to handle the location selection of petrol stations [24]. Montoya et al. present a mixed-integer mathematical model for vehicle routing problems that consider the environmental risk to select the best petrol station location. A heuristic algorithm is used to solve this mathematical model [25]. Khahro and Memon search the most appropriate land with Geographic Information System (GIS) for building petrol station [26]. Ayyildiz and Gumus define the petrol station location selection criteria and propose a fuzzy multi-criteria decision-making approach. The alternatives are evaluated considering a real case study [27].

As seen from the literature review, location selection of petrol stations is one of the topics handled in the academic literature. But, there is a very limited number of studies examining this problem as a multi-criteria decision-making problem. Also, to the best of our knowledge, there is no study for determining which petrol station(s) to serve during the lockdown, considering the pandemic conditions. Therefore, a comprehensive set of criteria is defined, and these criteria are weighted in this study. This study presents the most comprehensive criteria structure to determine which petrol station(s) to serve during lockdown which all the factors are included in terms of pandemic conditions. Further, this problem is solved in the spherical fuzzy environment to represent uncertainties and fuzziness in the decision-making process for the first time in the literature. To cope with this complex decision-making problem, spherical fuzzy VlseKriterijumska Optimizacija IKompromisno Resenje (VIKOR) is extended with AHP under a spherical fuzzy environment, and the Spherical Fuzzy AHP (SF-AHP) integrated spherical fuzzy VIKOR (SF-VIKOR) methodology is presented to the literature as a novel decision-making methodology.

Thanks to the proposed AHP and VIKOR combination under a spherical fuzzy environment, more detailed and comprehensive criteria set can be included in the evaluation process to make more accurate decisions in complex decision-making problems. These criteria can be grouped in a hierarchical structure and weighted more systematically. Thus, the opinions of decision-makers about the criteria can be integrated into the process more effectively. By using systematically weighted criteria in the VIKOR method, alternatives can be evaluated in more detail. In addition, with the proposed combination, the same experts can be consulted for criteria weighting and alternative evaluation, as well as different experts for criteria weighting and different experts for alternative evaluation.

In spherical fuzzy sets (SFS), decision-makers define a membership function on a spherical surface. Thus, by generalizing other fuzzy set extensions, they can independently assign the parameters of the membership function to a larger domain [1]. SFS give decision-makers more freedom, and less information distortion is lead [2]. Intuitionistic fuzzy sets (IFS), Pythagorean fuzzy sets (PFS), have some limitations that make these sets insufficient to handle uncertainty in information and capture the complete information. Namely, there is no function to represent the degree of hesitancy by decision-makers [3]. Recently, the SFS are introduced to literature address this. SFS provide an effective way to determine ambiguity in information more impressively and represent decision-makers' opinion better than the existing fuzzy sets [4]. SFS allow decision-makers to assign their hesitancy in the decision environment independently [1]. In this way, SFS enables the decision-making process to be more equivalent to human judgment, namely intelligent, so that SFS provide higher accuracy of determination of weight and evaluation of alternatives in the complex decision-making problems [5]. SFS can be considered as the integration of neutrosophic sets and PFS [6]. Decision-makers express their degree of hesitancy like membership degree and non-membership degree in SFS [7]. Thus, SFS collect the advantages of other fuzzy sets in a unique theory [1]. SFS eliminate some disadvantages of neutrosophic sets and PFS.

AHP is one of the most used multi-criteria decision-making methodologies used to prioritize the criteria [28]. Researchers used AHP because of its utilization of a simple hierarchical structure to handle complex decision-making problems [29]. Ease of use is one of the advantages of using AHP. It provides the opportunity to evaluate qualitative and quantitative criteria together by including the priorities of the decision-maker in the decision-making problems. A decision problem allows both subjective and objective thoughts to be included in the decision process. AHP makes the decision-making process formal and systematic and ensures that the right decisions are made. AHP method is an approach of MCDM, which analyzes the problem displayed in different levels of hierarchy [30]. It has a structure that simplifies complex problems [27]. AHP allows the decision-maker to measure the degree of consistency of their judgments. It is suitable for use in group decisions. The method uses the pairwise comparison of criteria. These comparisons allow decision-makers to determine the importance weight of criteria [31]. AHP enables decision-makers to make the right decision in complicated, complex, unorganized multi-criteria decision-making problems [32]. Determining the importance of criteria before solving the decision-making problem yields more reliable rankings of alternatives that reflect decision-makers' preferences more accurately [33]. For these reasons, we utilize AHP to determine the weights of criteria under a spherical fuzzy environment.

The VIKOR methodology focuses on ranking alternatives and selecting the best from a set of these alternatives. To determine the best option, many conflicting and non-commensurable criteria can be included [34]. The VIKOR methodology proposes an aggregating function that combines all considered criteria with their relative importance and a balance between the total satisfaction and individual regrets [35]. Aggregating function in VIKOR considers the distance from ideal solutions [36]. VIKOR enables the compromise solutions to resolve conflict [34]. Compromise means a mutual concession here [37]. This method helps decision-makers determine a compromise solution for the decision-making problem to reach a more accurate final decision [38]. For these reasons, SF-VIKOR is utilized to evaluate alternative stations to serve during the lockdown in this study.

In this study, the hierarchical criteria structure is constructed to define the criteria to determine the petrol station(s) to serve during the lockdown. Due to pandemic conditions, remote interviews with the expert group are conducted to take their opinions about criteria and alternatives. Then, the proposed methodology, which consists of SF-AHP and SF-VIKOR, is structured. The weights of each main and sub-criteria and specified alternative locations' evaluations are determined by the proposed hybrid decision-making methodology. The proposed methodology is applied to the Tuzla district of İstanbul to show its results and applicability.

This study is organized as follows: SFS are explained in Section 2. Related studies about SFS for multi-criteria decision-making are summarized in Section 3. The proposed novel methodology is presented in Section 4. Section 5 gives the real case study and sensitivity analysis of the proposed methodology. Comparative analysis is explained in Section 6. Finally, the results and future directions are given in the last section.

2. Spherical fuzzy sets

Fuzzy logic was first introduced to the literature by Zadeh [39]. The theory is suitable for subjective judgment and qualitative assessment in the evaluation processes of decision-making problems. The logic focuses on the rationality of uncertainty due to ambiguity. The linguistic approach is an effective method to solve uncertainty in information [40]. The multi-criteria decision-making problems may include more than one linguistic criteria. Different fuzzy sets can be used to define these linguistic criteria. IFS [41], PFS [42], type-2 fuzzy sets [43], hesitant fuzzy sets [44], and neutrosophic sets (NS) [45] are the most used sets in the literature [27].

The degree of membership of an element to the set is defined with μ_A, and the degree of non-membership to the set is defined with 1-μ_A in traditional fuzzy sets proposed by Zadeh. Therefore, the sum of the degrees of membership and non-membership equals 1. However, this situation is insufficient to explain the uncertainty situation in some problems encountered. So, Atanassov proposed the intuitionistic fuzzy set theory, which is the generalized version of the fuzzy set theory. While Zadeh's Fuzzy Set theory includes only the degree of membership defined in the [0,1] range, Atanassov added a non-membership degree to define the degree of membership in the IFS. Both the degree of membership and non-membership take value in the [0,1] range. Unlike the traditional fuzzy sets, the sum of the degree of membership and non-membership does not have to be 1 in IFS. Atanassov has defined a third parameter called the degree of hesitancy to complete this sum to 1.

Definition 1. Let X be a fixed set. An intuitionistic fuzzy number is shown as $\widetilde{I}$ in Eq. (2.1).:

$$\widetilde{I} \cong \{x, \widetilde{I}(\mu_{\widetilde{I}}(x), v_{\widetilde{I}}(x)); x \in X\} \tag{2.1}$$

where X is a fixed set in the function. $\mu_{\widetilde{I}}(x) : X \mapsto [0,1]$ and $v_{\widetilde{I}}(x) : X \mapsto [0,1]$ define the degree of membership and degree of non-membership of the element $x \in X$ to $\widetilde{I}$ respectively.

$$0 \leq \mu_{\widetilde{I}}(x) + v_{\widetilde{I}}(x) \leq 1; x \in X \tag{2.2}$$

The indeterminacy's degree is calculated by Eq. (2.3):

$$\pi_{\widetilde{I}}(x) = 1 - \mu_{\widetilde{I}}(x) - v_{\widetilde{I}}(x) \tag{2.3}$$

PFS were proposed by Yager [42] derived from IFS, which was originally proposed by Atanassov [41]. Unlike the IFS, the sum of membership and non-membership degrees can exceed 1, but the sum of their squares cannot be in PFS [46,47] as explained in Definition 2.

Definition 2. Let X be a fixed set. A Pythagorean fuzzy number is shown as $\widetilde{P}$ [46,47]:

$$\widetilde{P} \approx \{x, \mu_{\widetilde{p}}(x),\ v_{\widetilde{p}}(x); x \in X\} \tag{2.4}$$

where the function $\mu_{\widetilde{p}}(x) : X \mapsto [0,1]$ describes the degree of membership and $v_{\widetilde{p}}(x) : X \mapsto [0,1]$ defines the degree of non-membership of the element $x \in X$ to P respectively and for every $x \in X$, it holds:

$$0 \leq \mu_{\widetilde{p}}(x)^2 + v_{\widetilde{p}}(x)^2 \leq 1 \tag{2.5}$$

The indeterminacy ratio is obtained as in the following:

$$\pi_{\widetilde{p}}(x) = \sqrt{1 - \mu_{\widetilde{p}}(x)^2 - v_{\widetilde{p}}(x)^2} \tag{2.6}$$

SFS can also be used to handle ambiguity and fuzziness in linguistic expressions. SFS are defined with three dimensions like the IFS, PFS, and neutrosophic sets. But, functions are defined on a spherical surface to generalize fuzzy sets in SFS. So membership function can be assigned in a larger domain. Thus SFS provide more freedom to decision markers. In SFS sum and squared sum of membership, non-membership and indeterminacy ratio can be between 0 and 1, and all of them are defined in [0,1] independently as explained in Definition 3 [48].

Definition 3. Let X be a fixed set. A spherical fuzzy number is shown as $\widetilde{S}$:

$$\widetilde{S} \cong \{x, \widetilde{S}(\mu_{\widetilde{s}}(x),\ v_{\widetilde{s}}(x), \pi_{\widetilde{s}}(x)); x \in X\} \tag{2.7}$$

$\mu_{\widetilde{s}}(x) : X \mapsto [0,1]$, $v_{\widetilde{s}}(x) : X \mapsto [0,1]$ and $\pi_{\widetilde{s}}(x) : X \mapsto [0,1]$ define the membership function, non-membership function, and hesitancy function of the element $x \in X$ to $\widetilde{S}$, respectively.

$$0 \leq \mu_{\widetilde{s}}(x)^2 + v_{\widetilde{s}}(x)^2 + \pi_{\widetilde{s}}(x)^2 \leq 1; x \in U \tag{2.8}$$

3. Literature review

SFS are a new approach for multi-criteria decision-making process under a spherical fuzzy environment [48]. In SFS, functions are defined on a spherical surface to generalize fuzzy sets. So membership functions can be assigned in a larger domain [48]. SFS can be used to deal with the linguistic variables in the decision-making process. SFS are drawn the attention of many researchers and are later applied to many application areas. In this section, the multi-criteria decision-making literature related to the SFS is reviewed. Some remarkable studies based on SFS are given in Table 1.

Detailed summaries of the papers placed in Table 1 are as follows: K. Gundogdu and Kahraman present a novel SFs based VlseKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) methodology for

Table 1
Some remarkable multi-criteria decision-making studies based on SFS.

Author(s)	Year	Method	Subject	Type
K.Gundogdu and Kahraman [49]	2019	VIKOR	Warehouse site selection	Article
K.Gundogdu and Kahraman [50]	2019	WASPAS	Robot selection	Article
K.Gundogdu and Kahraman [48]	2019	TOPSIS	Supplier selection	Article
Zeng et al. [51]	2019	TOPSIS	Heavy rainfall assessment	Article
K.Gundogdu and Kahraman [52]	2019	TOPSIS	3d printer selection	Article
Barukab et al. [53]	2019	TOPSIS	Robot selection	Article
Rong et al. [54]	2019	TODIM	Illustrative example	Conference
K.Gundogdu and Kahraman [55]	2020	CODAS	Warehouse site selection	Conference
Liu et al. [56]	2020	TODIM	Shared bicycle evaluation	Article
Haktanir and Kahraman [57]	2020	FMEA	Car seats design	Book Chapter
K.Gundogdu and Kahraman [58]	2020	VIKOR	Waste disposal site selection	Conference
K.Gundogdu [59]	2020	MULTIMOORA	Personnel selection	Article
Bolturk [60]	2020	TOPSIS	Technology selection	Conference
K.Gundogdu and Kahraman [61]	2020	AHP	Robot selection	Conference
Kahraman et al. [62]	2020	QFD	Product development	Book Chapter
K.Gundogdu and Kahraman [63]	2020	AHP	Renewable energy site selection	Article
Balin [64]	2020	TOPSIS	Device selection	Article
Mathew et al. [65]	2020	AHP-TOPSIS	Manufacturing system selection	Article
Ashraf and Abdullah [66]	2020	TOPSIS-GRA	Emergency measure evaluation	Article
Ayyildiz and Taskin Gumus [27]	2020	AHP-WASPAS	Petrol station site selection	Article
Aydogdu and Gul [67]	2020	WASPAS	Illustrative example	Article
Kahraman et al. [68]	2020	TOPSIS	Hospital site selection	Conference
Sharaf and Khalil [69]	2020	TODIM	Safety equipment supplier selection	Article
Oztaysi et al. [70]	2020	AHP	Pricing model	Article
Akram et al. [37]	2021	VIKOR	Illustrative example	Article
Gul and Ak [71]	2021	FMEA-TOPSIS	Failure analysis	Article
K.Gundogdu [72]	2021	AHP	Hospital performance assessment	Book Chapter
Gul and Yucesan [73]	2021	TOPSIS	Hospital preparedness assessment	Article
K.Gundogdu and Kahraman [74]	2021	TOPSIS	Electric vehicle charging site selection	Book Chapter
Karasan et al. [75]	2021	CODAS	Livability index assessment	Book Chapter
Jaller and Otay [76]	2021	AHP-TOPSIS	Vehicle technology evaluation	Conference
Sharaf [77]	2021	PROMETHEE	Geothermal energy system evaluation	Book Chapter
Sharaf [78]	2021	VIKOR	Illustrative example	Book Chapter
Otay and Atik [79]	2021	AHP-WASPAS	Oil station site selection	Conference
Bolturk and K. Gundogdu [80]	2021	WASPAS	Manufacturing challenges prioritization	Book Chapter
Aydin and K. Gundogdu [81]	2021	MULTIMOORA	Industry 4.0 performance evaluation	Book Chapter
Demir and Turan [82]	2021	AHP	Crisis management	Article
Unal and Temur [83]	2021	AHP	Sustainable supplier selection	Conference
Unal and Temur [84]	2021	AHP	Waste management system selection	Conference
Erdogan et al. [85]	2021	DEMATEL-ANP-VIKOR	Vehicle driving system evaluation	Article
Liu et al. [86]	2021	TODIM-PROMETHEE	Health and safety risk assessment	Article
Nguyen et al. [87]	2021	AHP-WASPAS	COVID-19 intervention strategy evaluation	Article
Dogan [88]	2021	AHP	Process mining technology selection	Article
Singer and Sahin [89]	2021	AHP	Laminate flooring selection	Article
Menekse and Akdag [90]	2022	ARAS	Seismic vulnerability assessment	Conference
Menekse and Akdag [91]	2022	AHP-ELECTRE	Information technology governance analysis	Conference
Kahraman et al. [92]	2022	CRITIC	Supplier selection	Conference
Kahraman et al. [93]	2022	EXPROM	Wastewater treatment technology analysis	Conference
Oztaysi et al. [94]	2022	REGIME	Waste disposal site selection	Conference

warehouse location selection problem. Four different alternatives are evaluated using four different criteria via this methodology [49]. K. Gundogdu and Kahraman propose the WASPAS methodology for a spherical fuzzy environment. The industrial robot selection problem is handled as a case study. Four different criteria are used for selecting the best robot among five robots [50]. The supplier selection problem is focused on the study of K.Gundogdu and Kahraman. Technique for Order Preference by Similarity to an Ideal Solution (TOPSIS) methodology is extended to spherical fuzzy TOPSIS methodology for evaluating four different alternatives with respect to four criteria [48]. Zeng et al. develop a multi-criteria decision-making model to include different points of view for the covering-based spherical fuzzy rough environment. The assessment of heavy rainfall in Pakistan is performed using the TOPSIS methodology [51]. K.Gundogdu and Kahraman employ interval-valued spherical fuzzy TOPSIS methodology for 3D printer selection problems [52]. Barukab et al. identify four criteria to evaluate five robots via Spherical fuzzy TOPSIS methodology [53]. Combinative Distance-Based ASsessment (CODAS) methodology is extended with SFs to handle warehouse site selection problems [55]. Liu et al. evaluate the shared bicycles' index system via an extended spherical fuzzy TODIM (an acronym in Portuguese of Interactive and Multicriteria Decision-making) methodology [56]. Haktanir and Kahraman perform a literature review on fuzzy Failure mode and effects analysis (FMEA) and present a spherical fuzzy FMEA method for car seat design problem [57]. K.Gundogdu and Kahraman present a spherical fuzzy VIKOR methodology to waste management. The best site for a waste disposal facility is determined among five alternatives [58]. K.Gundogdu uses Multi-Objective Optimization by a Ratio Analysis plus the Full Multiplicative Form (MULTIMOORA) with SFS for personnel selection problem [59]. Bolturk uses TOPSIS methodology with spherical fuzzy numbers for the technology selection of automated storage and retrieval systems [60]. K.Gundogdu and Kahraman develop SF-AHP methodology for robot selection problem [61]. Kahraman et al. focus on the product development process. Quality function deployment (QFD) methodology is extended with SFs to handle this problem [62]. K.Gundogdu and Kahraman use spherical fuzzy AHP methodology for the site selection problem of the renewable energy facility. Neutrosophic AHP is performed to make a comparative analysis [63]. Balin employs spherical fuzzy TOPSIS methodology to evaluate stabilizing system alternatives for naval ships [64]. Ashraf and Abdullah utilize grey relational analysis (GRA) and TOPSIS to handle the uncertainties in emergency decision support modeling for COVID-19 [66]. Karasan et al. introduce spherical fuzzy CODAS methodology to determine livability indices for suburban places [75]. Sharaf propose spherical fuzzy preference ranking organization method of enrichment evaluation (PROMETHEE) methodology and solve two illustrative examples to show applicability of methodology [77]. Erdogan et al. combine Decision-making Trial and Evaluation Laboratory (DEMATEL), Analytical Network Process (ANP), and VIKOR to evaluate alternative autonomous vehicle driving systems in terms of comprehensive set of risk criteria [85]. Menekse and Akdağ develop spherical fuzzy extension of Additive Ratio ASsessment (ARAS) and perform seismic vulnerability assessment for university building [90]. Menekse and Akdag focus on information technology governance evaluation problem, and determine weight of criteria by SF-AHP, then evaluate alternatives by spherical fuzzyELimination Et Choice Translating REality (ELECTRE) [91]. Kahraman et al. propose CRiteria Importance Through Intercriteria Correlation (CRITIC) under spherical fuzzy environment to determine importance of criteria for supplier selection [92]. Spherical fuzzy version of EXtension of the PROMethee (EXPROM) is introduced to literature by Kahraman et al. to handle with wastewater treatment technology selection problem [93]. Oztaysi et al. propose novel spherical fuzzy REGIME to determine best site for waste disposal facility [94].

When detailed analyzes are applied about all these studies reviewed here, Figs. 1–3 are obtained, as presented below. Fig. 1 shows the types of studies reviewed.

When focused on Fig. 1, it is seen that the studies reviewed in this paper based on SFs are mostly published in international journals as articles with a rate of 51%. %31 of the studies are presented in conferences and published in proceeding books. Lastly, %18 of the studies are published as book chapters.

The usage of SFS in multi-criteria decision-making methodologies is newly introduced to the literature. The first related paper was published in 2019. The yearly distribution of the papers reviewed can be seen in Fig. 2.

According to Fig. 2, it can be said that the number of papers is increasing yearly. In 2019, just seven papers were reviewed, then seventeen papers were reviewed in this study that published in 2020. Twenty multi-criteria decision-making papers based on SFS published in 2021 are reviewed. Lastly, five papers are published in 2022. Different methodologies are used to solve decision-making problems. The methodologies used in reviewed papers can be seen in Fig. 3.

According to Table 1 and Fig. 3, eighteen different multi-criteria decision-making methodologies are employed in the reviewed forty-nine studies. Ten of these studies use hybrid methodologies to handle decision-making problems. AHP and TOPSIS are the most used methodology with fifteen and thirteen times, respectively. Then WASPAS, VIKOR, and TODIM are used six, five, and four times. Four different methodologies are used more than one time, and nine methodologies are used only one time. However, this is the first paper in which both AHP and VIKOR approaches are used together, according to Table 1. This makes the paper prominent in terms of methodology among the papers in the relevant literature.

According to a detailed multi-criteria decision-making literature review based on SFS applications, there is no study that combines VIKOR and AHP under an interval-valued spherical fuzzy environment. So, this study proposes a novel approach involving SF-AHP integrated SF-VIKOR, which is developed for the first time to deal with complex decision-making problems. Besides, using a fuzzy multi-criteria decision-making approach for the first time for determining the serving station during a pandemic is one of the first innovations made in this paper. Therefore, the study contains novelties in terms of both the method adopted and the field of application.

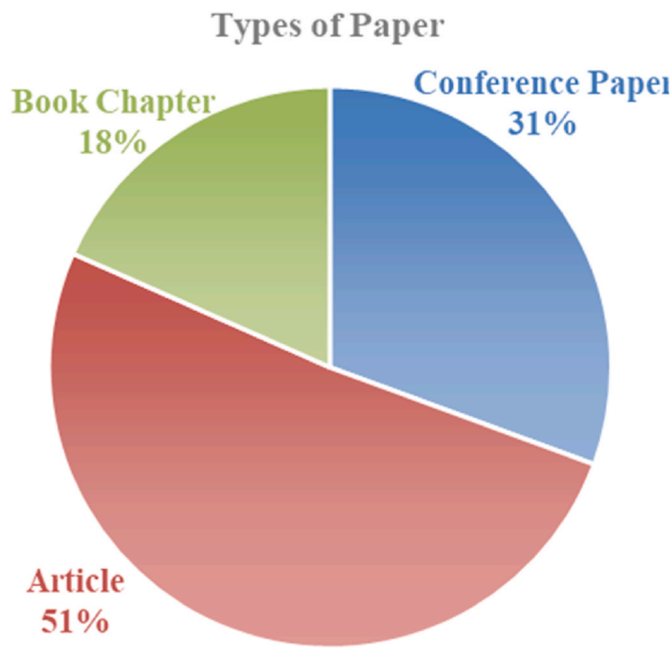

Fig. 1. Publications by types of papers.

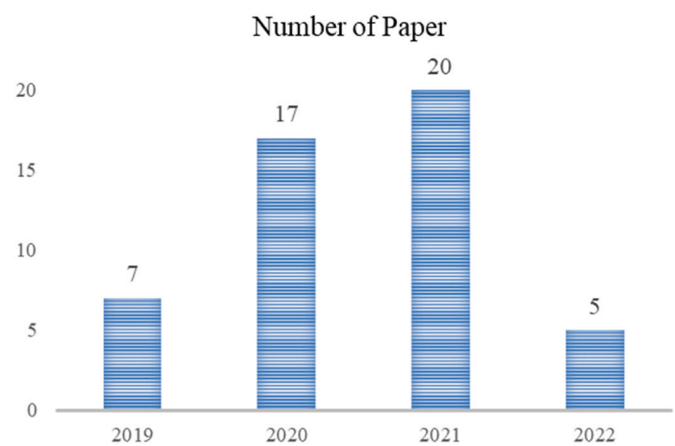

Fig. 2. The number of publications based on SFS for years.

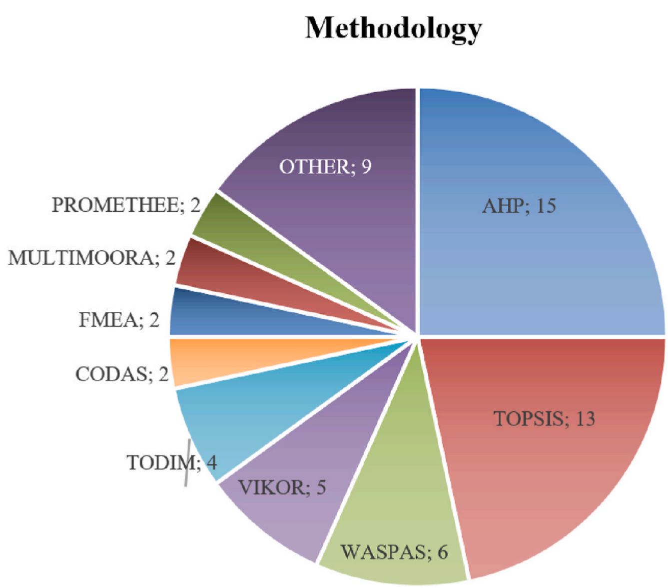

Fig. 3. The used methodologies in the papers reviewed.

4. The proposed methodology

The proposed fuzzy multi-criteria decision-making methodology that consists of SF-AHP integrated SF-VIKOR includes two main stages. In the first stage, the weights of each criteria level are determined by SF-AHP. Subsequently, SF-VIKOR is employed to rank alternatives using these weights. The proposed integrated methodology is given in Fig. 4, and it is detailed theoretically in the following steps.

4.1. Preliminaries of spherical fuzzy sets

Basic operations of spherical fuzzy numbers are shown as follows [63].

Definition 4. The addition of two spherical fuzzy numbers $\tilde{\alpha} = S\ (\mu_\alpha, v_\alpha, \pi_\alpha)$ and $\tilde{\beta} = S\ (\mu_\beta, v_\beta, \pi_\beta)$ is:

$$\tilde{\alpha} \oplus \tilde{\beta} = \tilde{S}\left(\sqrt{\mu_{\tilde{\alpha}}^2 + \mu_{\tilde{\beta}}^2 - \mu_{\tilde{\alpha}}^2\mu_{\tilde{\beta}}^2},\ v_{\tilde{\alpha}}v_{\tilde{\beta}}, \sqrt{(1-\mu_{\tilde{\alpha}}^2)\pi_{\tilde{\beta}}^2 + (1-\mu_{\tilde{\beta}}^2)\pi_{\tilde{\alpha}}^2 - \pi_{\tilde{\alpha}}^2\pi_{\tilde{\beta}}^2}\right) \tag{2.9}$$

Definition 5. The multiplication on two Spherical fuzzy numbers $\tilde{\alpha} = S\ (\mu_\alpha, v_\alpha, \pi_\alpha)$ and $\tilde{\beta} = S\ (\mu_\beta, v_\beta, \pi_\beta)$:

$$\tilde{\alpha} \otimes \tilde{\beta} = \tilde{S}\left(\mu_{\tilde{\alpha}}\mu_{\tilde{\beta}}, \sqrt{v_{\tilde{\alpha}}^2 + v_{\tilde{\beta}}^2 - v_{\tilde{\alpha}}^2 v_{\tilde{\beta}}^2}, \sqrt{(1-v_{\tilde{\alpha}}^2)\pi_{\tilde{\beta}}^2 + (1-v_{\tilde{\beta}}^2)\pi_{\tilde{\alpha}}^2 - \pi_{\tilde{\alpha}}^2\pi_{\tilde{\beta}}^2}\right) \tag{2.10}$$

Definition 6. Multiplication by a positive scalar ($\lambda > 0$):

$$\lambda\tilde{\alpha} = \tilde{S}\left(\sqrt{1-(1-\mu_{\tilde{\alpha}}^2)^\lambda}, v_{\tilde{\alpha}}^\lambda, \sqrt{(1-\mu_{\tilde{\alpha}}^2)^\lambda - (1-\mu_{\tilde{\alpha}}^2-\pi_{\tilde{\alpha}}^2)^\lambda}\right) \tag{2.11}$$

Definition 7. The positive power ($\lambda > 0$) of $\tilde{\alpha}$ is given:

$$\lambda\tilde{\alpha} = \tilde{S}\left(\sqrt{1-(1-\mu_{\tilde{\alpha}}^2)^\lambda}, v_{\tilde{\alpha}}^\lambda, \sqrt{(1-\mu_{\tilde{\alpha}}^2)^\lambda - (1-\mu_{\tilde{\alpha}}^2-\pi_{\tilde{\alpha}}^2)^\lambda}\right) \tag{2.12}$$

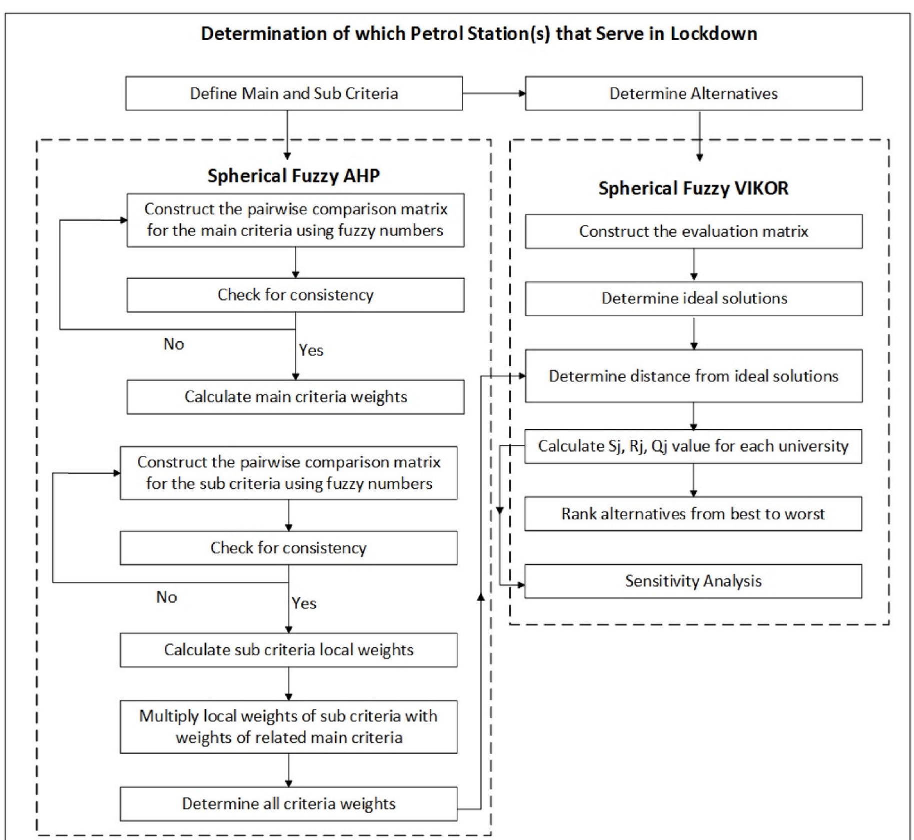

Fig. 4. The proposed methodology.

$$\tilde{\alpha}^{\lambda} = \tilde{S}\left(\mu_{\tilde{\alpha}}^{\lambda}, \sqrt{1-(1-v_{\tilde{\alpha}}^{2})^{\lambda}}, \sqrt{(1-v_{\tilde{\alpha}}^{2})^{\lambda}-(1-v_{\tilde{\alpha}}^{2}-\pi_{\tilde{\alpha}}^{2})^{\lambda}}\right) \tag{2.13}$$

Definition 8. Score value of $\tilde{\alpha}$ is calculated with Eq. (2.14).

$$\text{Score}(\tilde{\alpha}_{ij}) = (2\mu_{\tilde{\alpha}} - \pi_{\tilde{\alpha}})^2 - (v_{\tilde{\alpha}} - \pi_{\tilde{\alpha}})^2 \tag{2.14}$$

Definition 9. Euclidian distance between two Spherical fuzzy numbers $\tilde{\alpha} = S\ (\mu_{\tilde{\alpha}},\ v_{\tilde{\alpha}}, \pi_{\tilde{\alpha}})$ and $\tilde{\beta} = S\ (\mu_{\tilde{\beta}},\ v_{\tilde{\beta}}, \pi_{\tilde{\beta}})$ is determined:

$$\mathscr{D}(\tilde{\alpha}, \tilde{\beta}) = \sqrt{\left((\mu_{\tilde{\alpha}} - \mu_{\tilde{\beta}})^2 + (v_{\tilde{\alpha}} - v_{\tilde{\beta}})^2 + (\pi_{\tilde{\alpha}} - \pi_{\tilde{\beta}})^2\right)} \tag{2.15}$$

$$\tilde{\omega}_i = \tilde{S}\left(\sqrt{1-\prod_{j=1}^{n}\left(1-\mu_{\tilde{\alpha}_{ij}}^{2}\right)^{1/n}}, \prod_{j=1}^{n} v_{\tilde{\alpha}_{ij}}^{1/n}, \sqrt{\prod_{j=1}^{n}\left(1-\mu_{\tilde{\alpha}_{ij}}^{2}\right)^{1/n} - \prod_{j=1}^{n}\left(1-\mu_{\tilde{\alpha}_{ij}}^{2}-\pi_{\tilde{\alpha}_{ij}}^{2}\right)^{1/n}}\right) \tag{2.21}$$

4.2. Spherical fuzzy AHP

Step 1 The pairwise comparison matrix is constructed using information gained from anonymous experts. Linguistic terms (see Table 2 [48]) are used to define opinions.

Step 2 The spherical fuzzy pairwise comparison matrix is established using the spherical fuzzy numbers.

$$M = \begin{bmatrix} 1 & \tilde{\alpha}_{12} & \cdots & \tilde{\alpha}_{1n} \\ \tilde{\alpha}_{21} & 1 & \cdots & \tilde{\alpha}_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \tilde{\alpha}_{n1} & \tilde{\alpha}_{n2} & \cdots & 1 \end{bmatrix} \tag{2.16}$$

where $\tilde{\alpha}_{ij} = (\mu_{\tilde{\alpha}_{ij}},\ v_{\tilde{\alpha}_{ij}}, \pi_{\tilde{\alpha}_{ij}})$ represents the pairwise comparison between i and j.

Step 3 Score indices (SI) are calculated for each comparison ($\tilde{\alpha}_{ij}$).

$$SI = \sqrt{\left|100[(\mu_{\tilde{\alpha}_{ij}}^{2} - \pi_{\tilde{\alpha}_{ij}}^{2})^2 - (v_{\tilde{\alpha}_{ij}}^{2} - \pi_{\tilde{\alpha}_{ij}}^{2})^2]\right|} \quad \text{(for AMI, VHI, HI, SMI)} \tag{2.17}$$

$$SI = \frac{1}{\sqrt{\left|100[(\mu_{\tilde{\alpha}_{ij}}^{2} - \pi_{\tilde{\alpha}_{ij}}^{2})^2 - (v_{\tilde{\alpha}_{ij}}^{2} - \pi_{\tilde{\alpha}_{ij}}^{2})^2]\right|}} \quad \text{(for ALI, VLI, LI, SLI, EI)} \tag{2.18}$$

Table 2
Linguistic terms and spherical fuzzy scales of linguistic terms.

Linguistic Variables	Spherical Fuzzy Numbers			Score Index (SI)
	μ	v	π	
Absolutely low important - ALI	0.1	0.9	0	1/9
Very low important - VLI	0.2	0.8	0.1	1/7
Low important - LI	0.3	0.7	0.2	1/5
Slightly low important - SLI	0.4	0.6	0.3	1/3
Equal important - EI	0.5	0.5	0.4	1
Slightly high important - SHI	0.6	0.4	0.3	3
High important - HI	0.7	0.3	0.2	5
Very high important - VHI	0.8	0.2	0.1	7
Absolutely more important - AMI	0.9	0.1	0	9

Step 4 The pairwise comparison matrix is tested for consistency. Firstly, the consistency index (CI) of the matrix is calculated. λ_{max} is the largest eigenvalue of the pairwise comparison matrix, and n represents the number of criteria.

$$CI = \frac{\lambda_{max} - n}{n-1} \tag{2.19}$$

Then, the consistency ratio (CR) proposed by Saaty [95] is calculated.

$$CR = \frac{CI}{RI} \tag{2.20}$$

Random index (RI) depends on matrix order (n). RI is determined via the table [95]. The consistency ratio should be less than 0.1.

Step 5 The fuzzy weight for each criterion (ω_i) is calculated via a spherical weighted arithmetical mean.

Step 6 Fuzzy numbers are defuzzified to determine the weight of each criterion.

$$S_j = \sqrt{100\left[\left(3\mu_{\tilde{\omega}_j} - \frac{\pi_{\tilde{\omega}_j}}{2}\right)^2 - \left(\frac{v_{\tilde{\omega}_j}}{2} - \pi_{\tilde{\omega}_j}\right)^2\right]} \tag{2.22}$$

Step 7 The weights of criteria are normalized to determine the final weights.

$$w_j = \frac{S_j}{\sum_{j=1}^{n} S_j} \tag{2.23}$$

Step 8 All the above steps are repeated for each sub-criteria, and multiply local weights of the sub-criteria with the weight of related main criteria.

4.3. Spherical fuzzy VIKOR

Step 1 The decision matrix is established to evaluate alternatives according to criteria using linguistic terms using Table 2. Then linguistic terms are converted to spherical fuzzy numbers. Let $\tilde{X}_{ij}$ is the spherical fuzzy evaluation values of alternative i with respect to criterion j.

Step 2 The Positive ($\tilde{X}^*$) and Negative Ideal ($\tilde{X}^-$) solutions are determined for each criterion based on the score values. Score value of $\tilde{X}_{ij}$ is calculated with Eq. (2.24).

$$\text{Score}(\tilde{X}_{ij}) = (2\mu_{ij} - \pi_{ij})^2 - (v_{ij} - \pi_{ij})^2 \tag{2.24}$$

For the positive ideal solution:

Firstly, Eq. (2.24) is used to determine the score value of alternative *i* for criterion *j*, then the maximum scores in the decision matrix are determined as the positive ideal solution. The corresponding spherical fuzzy numbers are determined based on the maximum scores as in Eq.

(2.25) and Eq. (2.26).

$$\widetilde{X}^{*} = \left\{ C_i, \max_i < \text{Score}(X_{ij}) > \middle| i = 1, 2 \ldots m \right\} \quad (2.25)$$

$$\widetilde{X}^{*} = \{ C_1, (\mu_1^*, v_1^*, \pi_1^*), C_2, (\mu_2^*, v_2^*, \pi_2^*) \ldots\ldots C_m, (\mu_m^*, v_m^*, \pi_m^*) \} \quad (2.26)$$

where m represents the number of alternatives.

For the negative ideal solution:

Eq. (2.24) is used to determine the score value of alternative i for criterion j, then the minimum scores in the decision matrix are determined as the negative ideal solution. The corresponding spherical fuzzy numbers are determined based on the negative scores as in Eq. (2.27) and Eq. (2.28).

$$\widetilde{X}^{-} = \left\{ C_i, \min_i < \text{Score}(X_{ij}) > \middle| i = 1, 2 \ldots m \right\} \quad (2.27)$$

$$\widetilde{X}^{-} = \{ C_1, (\mu_1^-, v_1^-, \pi_1^*), C_2, (\mu_2^-, v_2^-, \pi_2^-) \ldots\ldots C_m, (\mu_m^-, v_m^-, \pi_m^-) \} \quad (2.28)$$

Step 3 S_i and R_i are calculated using Eq. (2.29) and Eq. (2.30) using criteria weights determined by spherical fuzzy AHP, respectively.

$$S_i = \sum_{j=1}^{n} w_j \frac{\mathscr{D}\left(\widetilde{X}_{ij}, \widetilde{X}_j^*\right)}{\mathscr{D}\left(\widetilde{X}_j^-, \widetilde{X}_j^*\right)} \quad (2.29)$$

$$R_i = \max_j \left(w_j \frac{\mathscr{D}\left(\widetilde{X}_{ij}, \widetilde{X}_j^*\right)}{\mathscr{D}\left(\widetilde{X}_j^-, \widetilde{X}_j^*\right)} \right) \quad (2.30)$$

where $\mathscr{D}$ represents the Euclidian distance as explained in Definition 9.

Step 4 Q_i is computed for each alternative:

$$Q_i = v \frac{(S_i - S^+)}{(S^- - S^+)} + (1 - v) \frac{(R_i - R^+)}{(R^- - R^+)} \quad (2.31)$$

where $S^+ = \min_i S_i; S^- = \max_i S_i$ and $R^+ = \min_i R_i; R^- = \max_i R_i$. v and $(1 - v)$ represent the weight of strategy of maximum group utility and individual regret, respectively.

Step 5 Rankings of alternatives are determined by the values of S_i, R_i and Q_i in ascending order.

Step 6 A compromise solution for the given set of criteria, the alternative $(a^{'})$, which is ranked the best by the measure the minimum Q_i is proposed if the following two conditions are satisfied [96]:

C1: "Acceptable advantage": $Q(a'') - Q(a^{'}) \geq D(Q)$ where (a'') is the second alternative in the ranking list by Q_i and $D(Q) = 1/(m - 1)$;

C2: "Acceptable stability in decision-making": Alternative $(a^{'})$ has to be best ranked by S or/and R.

If one of the conditions are not satisfied, then a set of compromise solutions is proposed (San Cristóbal, 2011):

- If C2 is not satisfied, Alternative $(a^{'})$ and Alternative (a'');
- If C1 is not satisfied, Alternative $(a^{'})$, Alternative (a'') … Alternative (Z) is determined by the relation $Q(Z) - Q(a^{'}) < D(Q)$ for maximum Z.

5. The numerical application for İstanbul

For this problem, thirteen candidate petrol stations in the Tuzla district of İstanbul are evaluated as a case study. As a serving petrol station selection problem during a lockdown, the problem of selecting one of the 13 alternative stations is addressed. İstanbul is located in the connection of Asia and Europe. The city, where more than 15 million people live, plays a key role in the economy of Turkey. Sixty percent of confirmed COVID-19 cases in Turkey are seen in İstanbul during the COVID-19 pandemic [97]. Also, more than fifty health institutions in the region treat many COVID-19 infected patients [98]. In this context, the services of public and private institutions in the region should continue during the lockdown. Therefore determining which fuel stations to serve during lockdown becomes more important.

5.1. The criteria determination

In the first stage of the proposed methodology, the main and sub-criteria are defined in order to determine the petrol stations to serve during a lockdown. A two-level hierarchical structure is constructed considering the criteria and their sub-criteria. Twenty-one different sub-criteria are taken into consideration to make a comprehensive analysis. These criteria are determined by literature review and consulting with anonymous experts. The criteria considered in this study are given in Fig. 5 in the hierarchical structure.

In order to make a comprehensive evaluation, all factors that may affect the decision-making process are tried to be included in the study. For this purpose, twenty-one different factors are determined as sub-criteria for this problem and classified under the titles of five different main criteria as *Accessibility, Facility Area, Products, Measures,* and *Population*.

As a result of the opinions received from the petrol station managers and the interviews with the academicians, the *Accessibility* of the petrol station which serves during lockdown is determined to be important for the effectiveness of the process. It is important to save time during transportation to the petrol station. In this context, the petrol station should be close to the state agencies that are open on lockdown. Petrol stations should be close to the industrial area, where factories that the basic needs of people are produced are located in terms of employee transportation. The fuel needs of ambulances that bring patients to health facilities, which have great importance in the pandemic process, should be met quickly in order to use them more effectively. Also, in terms of providing more effective transportation to medical staff, the petroleum station should be located close to the health institutions. During the lockdown period, people often go to their homes or businesses using the main roads. So the petrol station which serves during lockdown must be close to highways. Finally, it is desirable that the petrol station which serves during lockdown should be close to the city center, where people have to work during the quarantine process.

The *Facility Area* is important both for enabling social distance and meeting demands. Thus, it considers the available physical area of the station. The station should have a service area as large as possible to serve the customers. The high vehicle capacity determines the number of vehicles that can be served at the same time. The high number of employees is also important for operating the process more effectively. Auxiliary services cover lubrication, automatic car washing, spare parts supply, market, cold/hot food and beverage service, WC, etc. [27].

The third main criterion is *Products.* It covers product-related factors as product range, product capacity, price of products, and brand of products. Product range means the product range of the petrol station can serve. Product capacity is also important to provide uninterrupted service due to storage. Price is always important for the customers to choose a petrol station. The brand is important in terms of representing the trust and customer habits it provides to people.

Measures are added to the criteria hierarchy to represent COVID-19 effects on the petrol stations operating process. The managers of the petrol stations must provide accurate training about COVID-19 to their staff. The petrol station must be disinfected regularly. Warning and information should be located in different places of the station, regularly. The ventilation system should be capable of preventing the spread of the

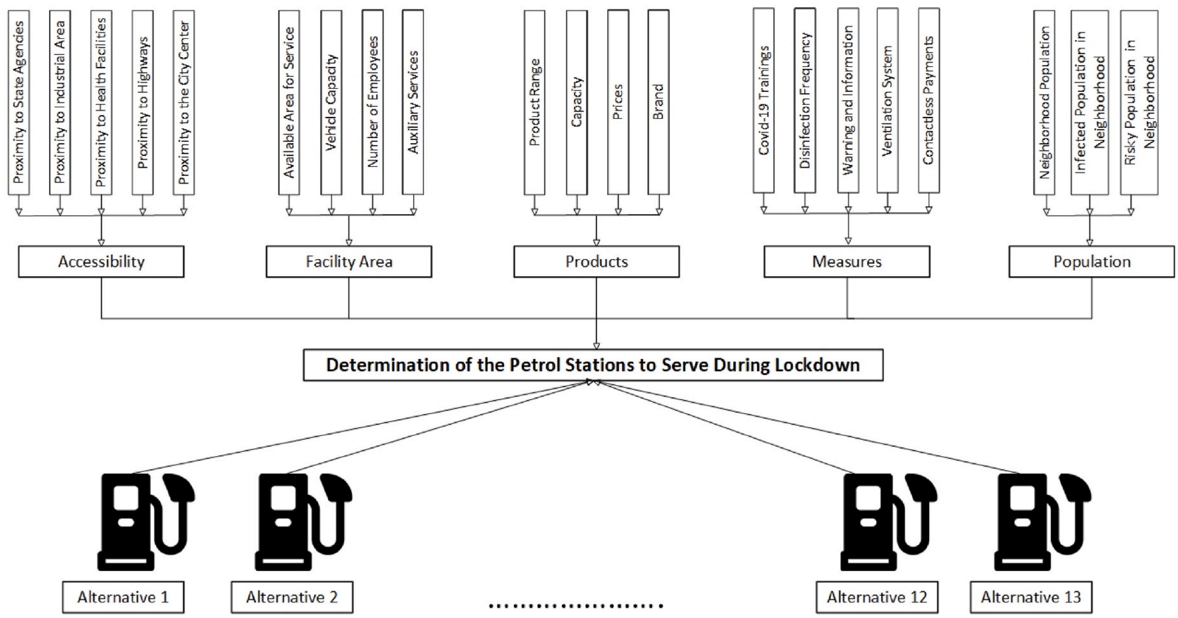

Fig. 5. The main and sub-criteria hierarchy.

virus in the facility. Besides, customers prefer to pay with contactless payment methods during the pandemic.

The last main criterion in this study is *Population.* It means the population density in the region where the petrol station is located. It includes total, infected, and risky populations. Risky population refers to people who have a chronic disease and are elder.

5.2. The weight calculation

Firstly, an expert group is created to take opinions about criteria weights and alternative evaluation of petrol stations. The expert group consists of five experts, including three academicians and two managers. Academicians from different departments of universities and one manager from the public company, and one manager from the private company are consulted to take their opinions about a handled problem. All academicians have expertise in public health and related topics. The managers work on transportation operations for their institutions. Remote interviews are conducted with the expert group to get their ideas because of pandemic conditions. Experts are first asked to evaluate the main and sub-criteria using linguistic terms given in Table 2.

The aggregated pairwise comparisons of the five main criteria are evaluated by the expert group via linguistic terms as given in Table 3.

Firstly, the pairwise comparison matrix is tested for consistency. For this purpose, the calculations given in Step 4 are conducted, and the matrix is determined to be consistent. Then, the SF-AHP is performed to determine the weights of the main criteria. The weights of the main criteria of *Accessibility, Facility Area, Products, Measures,* and *Population* are calculated as 0.24, 0.17, 0.15, 0.24, and 0.20, respectively. Two main criteria with the highest weights are determined as *Accessibility* and *Measures,* with 0.24. The *Population* is also an important main

Table 3
Pairwise comparison matrix for the main criteria.

	Accessibility	Facility Area	Products	Measures	Population
Accessibility	EI	SMI	HI	SMI	SMI
Facility Area	SLI	EI	SMI	LI	SLI
Products	LI	SLI	EI	LI	SLI
Measures	SLI	HI	HI	EI	SMI
Population	SLI	SMI	SMI	SLI	EI

Table 4
Pairwise comparison matrix for Accessibility.

	Proximity to State Agencies	Proximity to Industrial Area	Proximity to Hospitals	Proximity to Highways	Proximity to City Center
Proximity to State Agencies	EI	SLI	VLI	LI	LI
Proximity to Industrial Area	SMI	EI	VLI	SLI	LI
Proximity to Hospitals	VHI	VHI	EI	HI	SMI
Proximity to Highways	HI	SMI	LI	EI	SLI
Proximity to City Center	HI	HI	SLI	SMI	EI

Table 5
Pairwise comparison matrix for Facility Area.

	Available Area for Service	Vehicle Capacity	Number of Employees	Auxiliary Services
Available Area for Service	EI	VLI	LI	SMI
Vehicle Capacity	VHI	EI	SMI	AMI
Number of Employees	HI	SLI	EI	VHI
Auxiliary Services	SLI	ALI	VLI	EI

Table 6
Pairwise comparison matrix for Products.

	Range	Capacity	Prices	Brand
Range	EI	HI	HI	VHI
Capacity	LI	EI	SMI	HI
Prices	LI	SLI	EI	HI
Brand	VLI	LI	LI	EI

Table 7
Pairwise comparison matrix for Measures.

	Staff Education	Disinfection Frequency	Warning and Information	Ventilation System	Contactless Payments
Staff Education	EI	HI	SLI	HI	SLI
Disinfection Frequency	LI	EI	LI	SMI	LI
Warning and Information	SMI	HI	EI	HI	EI
Ventilation System	LI	SLI	LI	EI	LI
Contactless Payments	SMI	HI	EI	HI	EI

Table 8
Pairwise comparison matrix for Population.

	Neighborhood Population	Infected Population in Neighborhood	Risky Population in Neighborhood
Neighborhood Population	EI	AMI	HI
Infected Population in Neighborhood	ALI	EI	LI
Risky Population in Neighborhood	LI	HI	EI

Table 9
Local and final weights of sub-criteria.

Main Criteria	Sub-criteria		Local Weight	Final Weight	Rank
Accessibility	Proximity to State Agencies	C_{11}	0.127	0.031	19
	Proximity to Industrial Area	C_{12}	0.158	0.038	13
	Proximity to Hospitals	C_{13}	0.281	0.068	2
	Proximity to Highways	C_{14}	0.201	0.049	11
	Proximity to City Center	C_{15}	0.232	0.056	7
Facility Area	Available Area for Service	C_{21}	0.192	0.033	17
	Vehicle Capacity	C_{22}	0.362	0.063	3
	Number of Employees	C_{23}	0.301	0.052	9
	Auxiliary Services	C_{24}	0.145	0.025	20
Products	Range	C_{31}	0.342	0.049	10
	Capacity	C_{32}	0.264	0.038	14
	Prices	C_{33}	0.240	0.035	16
	Brand	C_{34}	0.154	0.022	21
Measures	COVID-19 Trainings	C_{41}	0.224	0.054	8
	Disinfection Frequency	C_{42}	0.160	0.039	12
	Warning and Information	C_{43}	0.240	0.058	5
	Ventilation System	C_{44}	0.135	0.033	18
	Contactless Payments	C_{45}	0.240	0.058	5
Population	Neighborhood Population	C_{51}	0.512	0.101	1
	Infected Population in Neighborhood	C_{52}	0.182	0.036	15
	Risky Population in Neighborhood	C_{53}	0.306	0.060	4

criterion with a weight of 0.20. The *Facility Area* and *Products* have lower weights than other main criteria. *Product* has the least importance weight among all main criteria with 0.15.

Then, the pairwise comparison matrices of the sub-criteria are constructed for each main criterion. Tables 4–8 give the sub-criteria pairwise comparison matrices for the *Accessibility, Facility Area, Product, Measures,* and *Population*, respectively.

After all, matrices are determined as consistent, and the weight calculation process is repeated to determine the local weights of each sub-criterion. The local weights of each sub-criterion are multiplied with their related main criterion weight to find the final weight of the related sub-criterion. So, the final criteria weights are determined as given in Table 9.

When Table 9 is analyzed, it is seen that the most important evaluation criterion is *Neighborhood Population.* In other words, it is determined that the most important factor when choosing a petrol station to serve during lockdown is the number of people living close to the station. Besides, "Proximity to Hospital", "Vehicle Capacity", and "Risky Population in Neighborhood" are the factors that should be evaluated as a priority when choosing a station. The least important criterion is found to be "Brand". That is, the brand of gasoline and other products appear to be the factor that should be taken into consideration at the end of the list while determining the petrol station in the case of the lockdown.

5.3. *Evaluation of alternatives*

After the criteria weights are calculated, the alternatives are evaluated according to the predetermined criteria. In determining alternatives, the districts in İstanbul are searched to apply the proposed methodology for the problem to show its applicability. At this point, Tuzla, a district of İstanbul, stands out with its proximity to the state and private sectors as it is a transportation hub. Therefore, the proposed fuzzy methodology is applied to select which station to serve in lockdown among alternative stations in Tuzla. In the application discussed here, the candidate stations are shown in Fig. 6 to serve during the lockdown.

The same experts are employed to ask their opinions about the alternatives considering the criteria determined before by using the linguistic terms in Table 2. Table 10 is created through the remote interviews, and the following evaluations are obtained.

After receiving criterion-alternative evaluations from experts the best and the worst values for each criterion were determined as given in Table 11. Therefore the ideal solutions are determined.

S_i, R_i and Q_i were calculated using the weights obtained from SF-AHP and the ideal solutions are given in Table 11. The threshold value (v) is determined as 0.5 to combine the S_i and the R_i [49]. S_i, R_i and Q_i values were calculated for each station and their rankings are determined with this way as given in Table 12.

Alternative 7 is determined as the best option according to Q_i scores. Alternative 7 satisfies the C2 condition (Acceptable stability in decision-

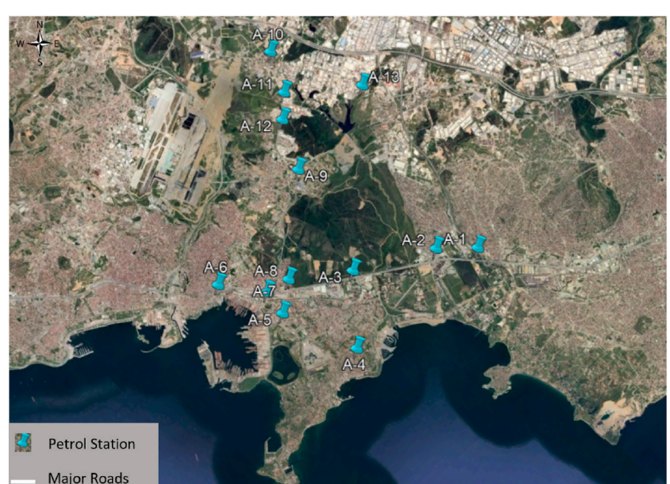

Fig. 6. Locations of alternatives.

Table 10
Criterion-alternatives evaluations with linguistic scale.

Alternative	C_{11}	C_{12}	C_{13}	C_{14}	C_{15}	C_{21}	C_{22}	C_{23}	C_{24}	C_{31}	C_{32}
Alternative 1	EI	SMI	AMI	VHI	SLI	LI	SMI	EI	LI	EI	SMI
Alternative 2	SLI	HI	VHI	VHI	LI	HI	VLI	LI	EI	EI	EI
Alternative 3	SMI	EI	AMI	VHI	SMI	SLI	SLI	SMI	SMI	SMI	SMI
Alternative 4	HI	ALI	EI	VLI	AMI	LI	EI	SMI	EI	EI	SMI
Alternative 5	VHI	LI	EI	SMI	SMI	SLI	SLI	EI	SMI	EI	SMI
Alternative 6	SMI	SLI	EI	HI	SLI	VLI	VLI	VLI	ALI	SLI	VLI
Alternative 7	AMI	SLI	HI	HI	SMI	HI	SMI	VHI	SLI	EI	HI
Alternative 8	VHI	EI	HI	VHI	SMI	EI	SMI	HI	EI	EI	SMI
Alternative 9	SMI	HI	LI	SLI	LI	VHI	SMI	VHI	VHI	HI	HI
Alternative 10	LI	VHI	ALI	HI	VLI	EI	SMI	SLI	SMI	HI	EI
Alternative 11	LI	AMI	VLI	EI	ALI	SLI	SLI	SLI	SMI	AMI	SLI
Alternative 12	VLI	VHI	VLI	EI	VLI	AMI	LI	SLI	VHI	VHI	SMI
Alternative 13	ALI	AMI	ALI	EI	VLI	VHI	SMI	VHI	VHI	VHI	HI
Alternative	C_{33}	C_{34}	C_{41}	C_{42}	C_{43}	C_{44}	C_{45}	C_{51}	C_{52}	C_{53}	
Alternative 1	SMI	LI	HI	SLI	EI	SMI	LI	SLI	SMI	SMI	
Alternative 2	ALI	HI	EI	HI	EI	SMI	HI	SLI	HI	SLI	
Alternative 3	SLI	SLI	EI	SLI	EI	EI	SLI	SMI	SLI	LI	
Alternative 4	EI	VHI	SMI	VHI	SMI	EI	VHI	VHI	LI	SLI	
Alternative 5	EI	VHI	SMI	VHI	SMI	EI	VHI	SMI	SLI	LI	
Alternative 6	SMI	LI	SLI	SLI	EI	EI	SLI	SLI	SMI	EI	
Alternative 7	HI	SMI	EI	SMI	EI	EI	SMI	SMI	EI	EI	
Alternative 8	HI	SMI	EI	SMI	EI	EI	SMI	SMI	SLI	EI	
Alternative 9	EI	VHI	SMI	VHI	EI	SMI	VHI	SLI	SLI	EI	
Alternative 10	VLI	EI	EI	EI	SMI	SMI	EI	LI	HI	HI	
Alternative 11	AMI	VLI	SLI	LI	SLI	HI	LI	VLI	HI	SMI	
Alternative 12	ALI	HI	EI	HI	EI	HI	HI	LI	HI	SMI	
Alternative 13	EI	VHI	EI	VHI	SMI	HI	VHI	LI	VHI	HI	

Table 11
The positive and negative solutions.

	C_{11}			C_{12}			C_{13}			C_{14}			C_{15}			C_{21}		
$\widetilde{X}^*$	0.9	0.1	0	0.9	0.1	0	0.9	0.1	0	0.8	0.2	0.1	0.9	0.1	0	0.9	0.1	0
$\widetilde{X}^-$	0.1	0.9	0.9	0.1	0.9	0.9	0.1	0.9	0.9	0.2	0.8	0.8	0.1	0.9	0.9	0.2	0.8	0.8
	C_{22}			C_{23}			C_{24}			C_{31}			C_{32}			C_{33}		
$\widetilde{X}^*$	0.6	0.4	0.3	0.8	0.2	0.1	0.8	0.2	0.1	0.9	0.1	0	0.7	0.3	0.2	0.9	0.1	0
$\widetilde{X}^-$	0.2	0.8	0.8	0.2	0.8	0.8	0.1	0.9	0.9	0.4	0.6	0.6	0.2	0.8	0.8	0.1	0.9	0.9
	C_{34}			C_{41}			C_{42}			C_{43}			C_4			C_{45}		
$\widetilde{X}^*$	0.8	0.2	0.1	0.7	0.3	0.2	0.8	0.2	0.1	0.6	0.4	0.3	0.7	0.3	0.2	0.8	0.2	0.1
$\widetilde{X}^-$	0.2	0.8	0.8	0.4	0.6	0.6	0.3	0.7	0.7	0.4	0.6	0.6	0.5	0.5	0.5	0.3	0.7	0.7
	C_{51}			C_{52}			C_{53}											
$\widetilde{X}^*$	0.8	0.2	0.1	0.8	0.2	0.1	0.7	0.3	0.2									
$\widetilde{X}^-$	0.2	0.8	0.8	0.3	0.7	0.7	0.3	0.7	0.7									

Table 12
The values of S_i, R_i and Q_i and rankings based on S_i, R_i and Q_i for each alternative.

Alternative	S_i	Rank	R_i	Rank	Q_i	Rank
Alternative 1	0.382	7	0.055	6	0.401	8
Alternative 2	0.438	11	0.055	6	0.490	9
Alternative 3	0.429	10	0.045	4	0.356	7
Alternative 4	0.338	4	0.038	3	0.121	2
Alternative 5	0.375	6	0.045	4	0.271	4
Alternative 6	0.586	13	0.055	6	0.722	12
Alternative 7	0.338	3	0.037	1	0.110	1
Alternative 8	0.358	5	0.037	1	0.142	3
Alternative 9	0.322	2	0.055	6	0.308	5
Alternative 10	0.416	9	0.066	10	0.583	11
Alternative 11	0.501	12	0.078	13	0.865	13
Alternative 12	0.407	8	0.066	10	0.569	10
Alternative 13	0.268	1	0.066	10	0.350	6

making) because it is determined as the best alternative for both R_i and Q_i scores. But, the C1 condition (Acceptable advantage) is not satisfied for Alternative 7. Since the C1 condition is not fulfilled for Alternative 7, inequality of $Q(a'') - Q(a') \geq D(Q)$ should be checked to find the compromise solution. Accordingly, the difference between Alternative 7 and Alternative 4 (second alternative for Q_i scores) is less than 0.083. For this reason, Alternative 7 and Alternative 4 should be considered as compromise the best options. If only one of them is selected, Alternative, and if two of them are selected, Alternative 7 and Alternative 4 should be determined as the best options together.

Alternative 7 is the best alternative to serve in lockdown according to the results of the proposed methodology. Alternative 7 stands out with its proximity to the city center, hospital, highways. It also has a bigger facility area and has more employees to serve customers. Alternative 4 is also a good option to serve in lockdown. Alternative 11 is the worst option to serve in lockdown for these reasons, which are its accessibility and measures.

5.4. Sensitivity analysis

In this subsection, a sensitivity analysis is performed to show the applicability and reliability of the proposed hybrid decision-making methodology due to the changes in parameters. The analysis is performed by the change in threshold value (v). The value is increased by 0.1 for each step, which changes from 0.1 to 0.9. The robustness of the decision is shown in this way. The final rankings of all alternatives ac-

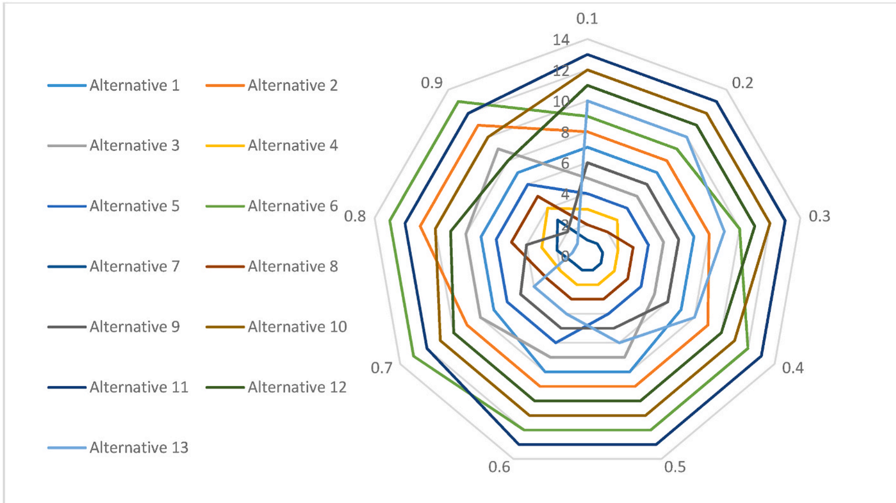

Fig. 7. The ranking of alternatives according to different threshold values.

cording to different threshold values are given in Fig. 7.

The effect of threshold values on the order of the alternatives is measured by sensitivity analysis. The reason for this is that each alternative has different values for both the weighted sum model and the weighted product model. As can be seen from Fig. 7, *Alternative 7*, which is the best alternative in the current situation, takes first place in all scenarios except 0.8 and 0.9, too. This means that the alternative, which is currently in the first place, is a good option the most cases to serve during a lockdown. The ranking of *Alternative 8*, which currently takes second place, is increased while the threshold value increases; so that it becomes the fifth-best alternative to serve during lockdown for 0.9. The reason for this may be that *Alternative* 8 has a relatively bad value for R_i (the weighted maximum regret). As the threshold value increases, the effect of the R_i increases. *Alternative 4* is also a good option for all scenarios. As the threshold value increases, *Alternative 13* achieves better rankings. This means *Alternative* 13 has a better result for the R_i than the S_i (the weighted total regret).

6. Comparative analysis

A comparative analysis is conducted to further validate the robustness and effectiveness of the proposed methodology to evaluate alternatives. SF-WASPAS methodology is employed to test the effectiveness of SF-VIKOR. The criteria weights determined by SF-AHP are used to evaluate alternatives for this purpose. The steps of SF-WASPAS are given below [27]:

Step 1 Weighted sum model $(\tilde{Q}_i^1)$ is calculated for each alternative.

$$\tilde{Q}_i^1 = \sum_{i=1}^{m} \tilde{x}_{ijw} \tag{5.1}$$

$$\tilde{x}_{ijw} = \tilde{x}_{ij} w_j = \tilde{S}\left(\sqrt{1-\left(1-\mu^2_{\tilde{x}_{ij}}\right)^{w_j}},\, v^{w_j}_{\tilde{x}_{ij}},\, \sqrt{\left(1-\mu^2_{\tilde{x}_{ij}}\right)^{w_j}-\left(1-\mu^2_{\tilde{x}_{ij}}-\pi^2_{\tilde{x}_{ij}}\right)^{w_j}}\right) \tag{5.2}$$

$$\tilde{x}_{i1w} \oplus \tilde{x}_{i2w} = \tilde{S}\left(\sqrt{\mu^2_{\tilde{x}_{i1w}}+\mu^2_{\tilde{x}_{i2w}}-\mu^2_{\tilde{x}_{i1w}}\mu^2_{\tilde{x}_{i2w}}},\, v_{\tilde{x}_{i1w}} v_{\tilde{x}_{i2w}},\, \sqrt{\left(1-\mu^2_{\tilde{x}_{i1w}}\right)\pi^2_{\tilde{x}_{i2w}}+\left(1-\mu^2_{\tilde{x}_{i2w}}\right)\pi^2_{\tilde{x}_{i1w}}-\pi^2_{\tilde{x}_{i1w}}\pi^2_{\tilde{x}_{i2w}}}\right) \tag{5.3}$$

Step 2 Weighted product model $(\tilde{Q}_i^2)$ is calculated for each alternative.

$$\tilde{Q}_i^2 = \prod_{j=1}^{n} \tilde{x}_{ij}^{w_j} \tag{5.4}$$

$$\tilde{x}_{ij}^{w_j} = \tilde{S}\left(\mu^{w_j}_{\tilde{x}_{ij}},\, \sqrt{1-\left(1-v^2_{\tilde{x}_{ij}}\right)^{w_j}},\, \sqrt{\left(1-v^2_{\tilde{x}_{ij}}\right)^{w_j}-\left(1-v^2_{\tilde{x}_{ij}}-\pi^2_{\tilde{x}_{ij}}\right)^{w_j}}\right) \tag{5.5}$$

$$\tilde{x}_{i1}^{w_1} \otimes \tilde{x}_{i2}^{w_2} = \tilde{S}\left(\mu_{\tilde{x}_{i1}^{w_1}}\mu_{\tilde{x}_{i2}^{w_2}},\, \sqrt{v^2_{\tilde{x}_{i1}^{w_1}}+v^2_{\tilde{x}_{i2}^{w_2}}-v^2_{\tilde{x}_{i1}^{w_1}}v^2_{\tilde{x}_{i2}^{w_2}}},\, \sqrt{\left(1-v^2_{\tilde{x}_{i1}^{w_1}}\right)\pi^2_{\tilde{x}_{i2}^{w_2}}+\left(1-v^2_{\tilde{x}_{i2}^{w_2}}\right)\pi^2_{\tilde{x}_{i1}^{w_1}}-\pi^2_{\tilde{x}_{i1}^{w_1}}\pi^2_{\tilde{x}_{i2}^{w_2}}}\right) \tag{5.6}$$

Step 3 The threshold value (λ) is determined to combine $\tilde{Q}^1$ and $\tilde{Q}^2$.

$$\lambda\tilde{Q}_i^1 = \tilde{S}\left(\sqrt{1-\left(1-\mu^2_{\tilde{Q}_i^1}\right)^{\lambda}},\, v^{\lambda}_{\tilde{Q}_i^1},\, \sqrt{\left(1-\mu^2_{\tilde{Q}_i^1}\right)^{\lambda}-\left(1-\mu^2_{\tilde{Q}_i^1}-\pi^2_{\tilde{Q}_i^1}\right)^{\lambda}}\right) \tag{5.7}$$

$$(1-\lambda)\tilde{Q}_i^2 = \tilde{S}\left(\sqrt{1-\left(1-\mu^2_{\tilde{Q}_i^2}\right)^{(1-\lambda)}},\, v^{1-\lambda}_{\tilde{Q}_i^2},\, \sqrt{\left(1-\mu^2_{\tilde{Q}_i^2}\right)^{(1-\lambda)}-\left(1-\mu^2_{\tilde{Q}_i^2}-\pi^2_{\tilde{Q}_i^2}\right)^{(1-\lambda)}}\right) \tag{5.8}$$

Table 13
Weighted sum model and weighted product model.

	Weighted Sum Model $(\tilde{Q}_i^1)$			Weighted Product Model$(\tilde{Q}_i^2)$		
	μ_i	v_i	π_i	μ_i	v_i	π_i
Alternative 1	0.44	0.65	0.22	0.37	0.71	0.23
Alternative 2	0.42	0.67	0.21	0.34	0.75	0.20
Alternative 3	0.44	0.65	0.23	0.38	0.71	0.24
Alternative 4	0.48	0.62	0.21	0.38	0.72	0.21
Alternative 5	0.44	0.65	0.23	0.39	0.70	0.24
Alternative 6	0.32	0.76	0.23	0.27	0.79	0.20
Alternative 7	0.47	0.62	0.24	0.44	0.65	0.25
Alternative 8	0.45	0.63	0.25	0.43	0.65	0.26
Alternative 9	0.47	0.63	0.20	0.40	0.69	0.22
Alternative 10	0.40	0.69	0.22	0.31	0.77	0.19
Alternative 11	0.41	0.70	0.17	0.27	0.81	0.16
Alternative 12	0.43	0.67	0.19	0.32	0.77	0.17
Alternative 13	0.50	0.60	0.17	0.36	0.75	0.16

Table 14
The final ranking of alternatives.

Ranking	Alternative	Spherical Fuzzy Score			Final Score
		μ_i	v_i	π_i	
1	Alternative 7	0.610	0.400	0.302	0.662
2	Alternative 8	0.595	0.412	0.317	0.597
3	Alternative 9	0.584	0.435	0.262	0.507
4	Alternative 4	0.584	0.444	0.264	0.492
5	Alternative 13	0.589	0.450	0.207	0.471
6	Alternative 5	0.561	0.453	0.298	0.424
7	Alternative 3	0.556	0.461	0.296	0.397
8	Alternative 1	0.556	0.463	0.285	0.390
9	Alternative 2	0.524	0.501	0.264	0.242
10	Alternative 12	0.519	0.514	0.233	0.196
11	Alternative 10	0.490	0.536	0.270	0.126
12	Alternative 11	0.481	0.561	0.219	0.044
13	Alternative 6	0.414	0.601	0.289	−0.047

Step 4 The relative weights are calculated for each alternative.

$$\widetilde{Q}_i = \lambda \widetilde{Q}_i^1 + (1-\lambda)\widetilde{Q}_i^2 \tag{5.9}$$

Step 5 Fuzzy numbers are defuzzified to determine the final scores of the alternatives.
Step 6 Alternatives are ranked according to the final score.

After receiving criterion-alternative evaluations from experts, the weighted sum model and the weighted product model are calculated. By taking into account the criteria weights obtained before, the weighted sum model and the weighted product model results are as in Table 13.

The threshold value (λ) is determined as 0.5 to. Then, the weighted sum model and the weighted product model are combined. The relative weights are calculated individually. Lastly, spherical fuzzy numbers are defuzzified to determine the final scores of each alternative. The alternatives are ranked according to their final scores, as given in Table 14.

According to the results obtained, Alternative 7 has the highest score with 0.662. The best option is determined the same as the SF-VIKOR application. It is followed by Alternative 8 and Alternative 9 with scores of 0.597 and 0.507, respectively. The two alternatives with the lowest scores are determined as Alternative 11 and Alternative 6 with 0.044 and −0.047. The worst two options are the same as the proposed methodology again. Fig. 8 demonstrates the proposed methodology results compared to those of the SF-WASPAS application. As can be seen in Fig. 8, the ranking order is similar to the result of the proposed methodology.

Comparative analysis shows that a very robust decision for the determining station is obtained from SF-VIKOR, as shown in Fig. 8. Although the methodology changed, the ranking of thirteen alternatives is not changing too much. According to the results of comparative analysis, it can be that the proposed integrated methodology is consistent with the other decision-making methodology. The SF-WASPAS method considers both the weighted sum model and weighted product model, namely two distance-based models, to make a decision whilst the SF-VIKOR methodology takes into account local dominance and overall advantage. Deriving the compromise solutions that aim to minimize individual regret and maximize the group utility is another advantage of the SF-VIKOR methodology compared with the SF-WASPAS methodology. As for the SF-WASPAS, it does not consider both the distances from the ideal solutions and their relative importance. Meanwhile, the compromise solution derived thanks to the SF-VIKOR method is the generally closest solution to the positive ideal solution; however, the solution enabled by the SF-WASPAS is not always the closest to the positive ideal solution.

As a result, the SF-VIKOR methodology not only provides a solution closer to the ideal but also provides a balance between the minimum individual regret for the "opponent" and maximum group utility of the "majority". In summary, the SF-VIKOR provides more valid and feasible results than other methods. Likewise, SF-VIKOR methodology is easier to apply decision-making problems, and it has less complexity. Therefore it provides a faster decision in complex decision-making problems.

7. Conclusion

The COVID-19 pandemic, which spread almost all over the world in a very short time with the effect of increasing human mobility with the increase in international trade and interaction, has progressed much faster than other epidemics experienced by human beings. It is not expected for countries to be fully prepared for a pandemic that spreads so rapidly and threatens human life. Therefore, the fight of countries against the pandemic depends on their existing infrastructure and the structure of their populations. For this reason, countries have sometimes implemented lockdowns. In order to provide basic needs during these lockdown times, some institutions need to continue their operations. In this context, determining which of the petrol stations, which are important stakeholders for transportation, will remain open during a lockdown has become a problem to be solved for city planners.

In this paper, the determination of the petrol stations to serve during the COVID-19 lockdown is taken into account and handled as a multi-criteria decision-making problem. Literature review and opinions from experts are used to identify the main and sub-criteria. Then, an expert

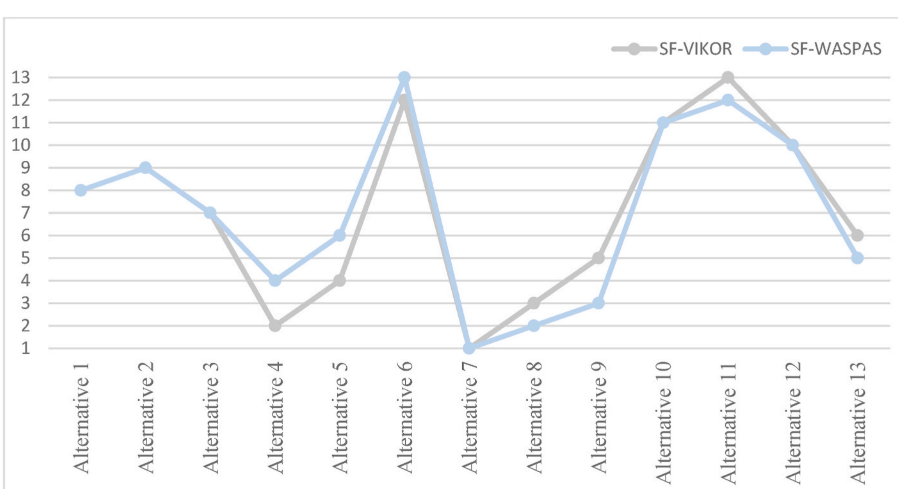

Fig. 8. The scores of the alternatives for both SF-VIKOR and SF-WASPAS.

group that includes both academicians from different departments of universities and managers from public and private sectors is created to take opinions about criteria weights and alternative evaluation of petrol stations. İstanbul is selected to perform a case study; thirteen petrol stations are evaluated as alternatives. Then, the SF-AHP integrated SF-VIKOR methodology is structured; the problem is solved by this methodology, and the best alternative is determined to serve during a lockdown. A sensitivity analysis is performed to explain and analyze the proposed methodology results. Finally, the results are compared with SF-WASPAS.

This study considers five main criteria as Accessibility, Facility Area, Products, Measures, and Population. According to the results, managers and city planners should pay special attention to Accessibility and Measures. The accessibility of the petrol station is important in the context of meeting basic needs during the lockdown process. In this way, the time spent on the road will decrease, and the probability of people getting infected by contacting fewer people will decrease. Petrol stations, which are located close to areas where people are concentrated even during lockdown times, are effective in meeting demand. In addition, in these periods when ambulances work intensively, it is a necessity to determine the service stations close to the hospitals for effective management of the process. Ensuring the transportation of personnel working in hospitals, public and private institutions serving during the lockdown to their workplaces has also gained importance during the pandemic process.

In terms of Measures, by placing warning and informative posters and brochures at the stations, it is necessary for the customers to get service and meet their needs by contacting minimum people. In addition, by using more modern payment methods, such as contactless payment, the use of cash, which people come into contact with frequently and which is likely to be contaminated, should be minimized. This study also suggests the capacity of stations should be increased, and the number of employees should be decreased.

The contributions of the paper to the literature and application can be specified as follows: (1) The factors that play a key role in petrol station selection problem during the COVID-19 pandemic are determined and classified; (2) The most important factors for the determination of the petrol stations to serve during lockdown are determined in the fuzzy environment; (3) A real case application in is performed to show the reliability and applicability of the proposed hybrid decision-making methodology; (4) Thirteen different stations are evaluated according to the criteria determined, and the best one is selected to serve; (5) It is aimed that, the proposed hybrid decision-making methodology can be used as a guide by public or private organizations to improve their operations to prevent spreading of COVID-19 by reducing the travel, especially their facilities and in nearby settlements.

Nevertheless, this study carries certain limitations. First, the finding may be subject to a limited number of evaluation criteria with a hierarchal structure. One future study could extend the evaluation criteria with different aspects (i.e., financial, social) and inner factors of them. Second, consulted expert group in the application a potential limitation of the study. Reaching and consulting experts' opinions were challenging because of the pandemic. Expert opinions were taken through remote interviews instead of face-to-face interviews. Therefore the number of consulted experts can be increased. Third, the study is conducted in Istanbul, Turkey, which may not be generalized to other countries. The study can be modified and improved for other countries.

This study shows that multi-criteria decision-making is applicable for determining petrol stations to serve in lockdown, in part due to the numerous conflicting decision criteria present and the ability of multi-criteria decision-making methodologies to cope with the multidimensionality of the problem. However, frequently, different multi-criteria decision-making methods can yield different results when used to the same complex decision-making problem. Therefore, we examined the application of one of the widely applied methodologies, namely WASPAS, for the handled problem. The results show that the best alternative is valid for comparative analysis. As a future direction, Different multi-criteria decision-making methods or heuristics can be included and evaluated to identify similarities and differences in the different methods and the obtained results, and also consider their applicability in the handled problem. Integrated multi-criteria decision-making methodologies can improve the precision of determining petrol stations to serve in lockdown. Finally, different optimization and decision-making methods can be utilized to achieve different purposes, such as sorting, ranking, clustering, classification, along with determining the best alternative and the importance levels of criteria.

Author statement

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Ertugrul Ayyildiz is a PhD candidate. He is now a PhD student at Yildiz Technical University, İstanbul Turkey. He receives her MSc in Industrial Engineering from Karadeniz Technical University in 2017. His research interests includes mixed integer programming, artificial neural networks, multi criteria decision making and fuzzy logic. He has published many papers in highly cited journals.

Alev Taskin Gumus received BSc and MSc degrees in Industrial Engineering from Yildiz Technical University in 2001 and 2003, respectively. She also received PhD in Industrial Engineering from Yildiz Technical University in 2007. She is now Professor in Industrial Engineering from Yildiz Technical University. She has published many papers in highly cited journals as Transportation Research Part E, Transportation Research Part A, Computers & Industrial Engineering, International Journal of Production Research, Applied Soft Computing and etc. Her research interests are in decision analysis, humanitarian logistic, fuzzy sets.