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ORIGINAL PAPER

A decision-making framework for COVID-19 infodemic management strategies evaluation in spherical fuzzy environment

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Abstract

100 years after the Spanish flu, the COVID-19 crisis showed that large-scale epidemics and pandemics do not belong to the past. On the report of the World Health Organization, COVID-19 is the most significant public health problem of the twenty-first century. Like previous epidemics, the current crisis is accompanied by uncertainty, mistrust, doubt and fear, and this has led to an infodemic connection to the epidemic. So not only are we fighting an epidemic, but also, we are brawling an infodemic. To reduce the social and economic consequences and harmful effects of infodemic health, and to overcome it, we need to implement strategies against infodemic. Evaluating strategies based on multiple characteristics can be considered multi-criteria decision-making (MCDM) problem. According to the literature, there is no study that aims on proposing an integrated approach to evaluate infodemic management strategies under uncertain environment. Therefore, in this paper, an integrated framework based on the extended version of best–worst method (BWM) and Combined Compromise Solution (CoCoSo) methods under a spherical fuzzy set (SFS) is developed for the first time to address the COVID-19 infodemic management strategies selection. Initially, the criteria are weighted using the developed SFS BWM which reduces uncertainty in pairwise comparisons. In the next step, the 15 selected strategies are analyzed and ranked using SFS CoCoSo. The outputs of this paper illustrate that online tools for fact checking COVID-19 information and engage and empower communities are placed in the first and second priorities, respectively. The comparison of ranking results SFS-CoCoSo with other MCDM methods demonstrates the performance of the proposed approach and its ranking stability.

Keywords Infodemic · Covid-19 · Multi-criteria decision-making · Best–worst method · CoCoSo · Spherical fuzzy set

1 Introduction

For the first time in China on December 31, 2019, pneumonia of undisclosed cause was reported to the World Health Organization (WHO) Country Office in China in Wuhan, China. The disease was later named COVID-19 and gradually spread to six continents, becoming a global threat with the announcement of the WHO on March 11, 2020. An epidemic of an infectious disease in a geographical area can lead to death and political, social, and economic problems (Ahmad and Rathore 2020). Figure 1 shows the start process of COVID-19. The virus is mainly transmitted through coughing or sneezing, breathing and talking to an infected person. The droplets coming out of the infected person enter the eyes, mouth and nose of a healthy person (Dave et al. 2021) The world has so far seen worse epidemics than Covid-19 with very high mortality in which millions have lost their lives and suffered great economic damage. However, the devastating global impact of the current Covid-19 pandemic seems unprecedented. Globally, as of 7 March 2022, there have been 445,096,612 confirmed cases of COVID-19, consisting of 5,998,301deaths, announced to WHO (Disease 2022). Figure 2 shows the prevalence of COVID-19 in the world. During the COVID-19 epidemic, thousands lost their jobs, and many businesses and service providers were forced to stop due to economic hardship. Due to the unknown nature of this disease and the unavailability of appropriate treatments during this period, measures were taken to combat

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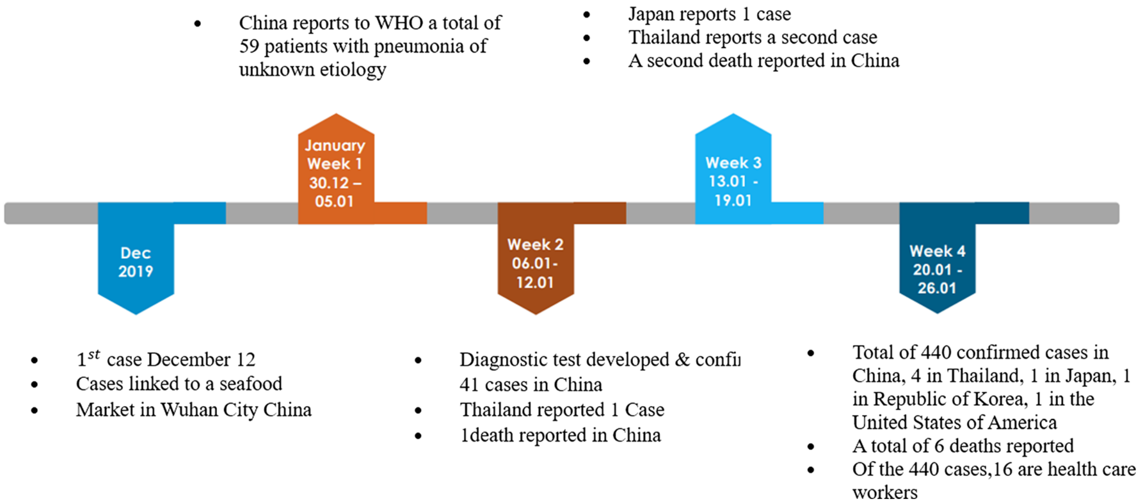

Fig. 1 The start processes of COVID-19

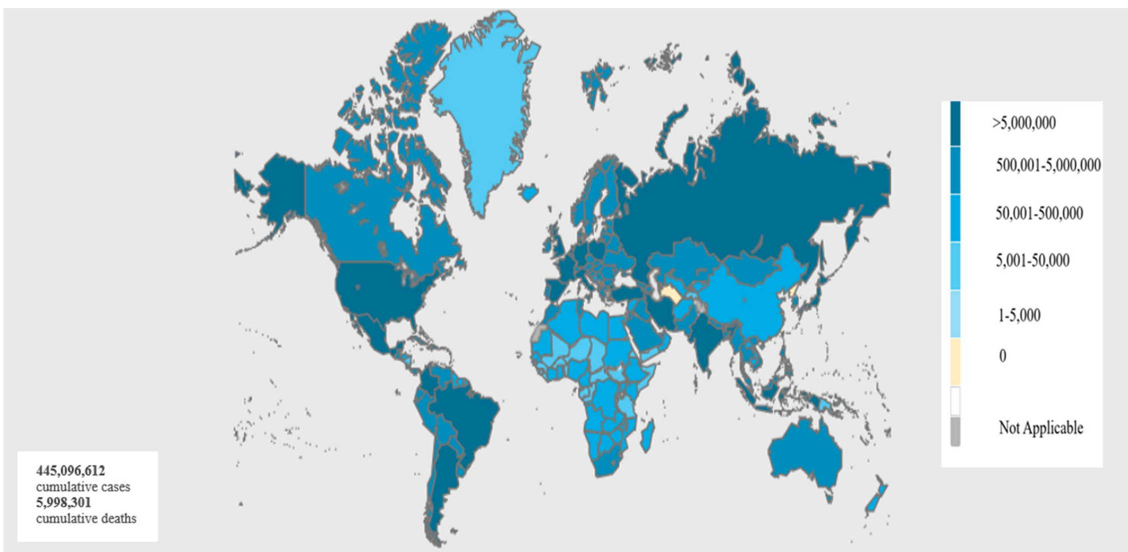

Fig. 2 The prevalence of COVID-19 in different sectors of the world in 2022

this unknown virus. For example, long-term quarantines, bans on internal and external borders, and closures of workplaces and schools were carried out (Viscusi 2020). Many instructions were also issued, including public health, such as using gloves and masks, washing hands, and cleaning surfaces (Nguyen et al. 2021; West et al. 2020).

Along with the epidemic of this unknown disease, vain ideas were spread all over the world through social media such as TikTok, WhatsApp, Twitter, and Facebook. For example, in March 2020, it was reported in the virtual media that the virus is a Chinese deception. And do not worry, you can kill the virus by pressing the hot air of the hairdryer (Buchanan 2020). On February 15, 2020, Director-General of the WHO, Tedros Adhanom Ghebreyesus, announced that the epidemic was went along with an infodemic (Conference). Infodemic refers to the mass of information that occurs during an outbreak of the disease, and a part of this information is precise and a part is not (Tangcharoensathien et al. 2020). Indeed, like epidemics, this information is disseminated to people through digital and physical information systems. And it becomes difficult for the general public to discover accurate and dependable information and advice (Organization 2020). During epidemics, people need accurate information and the right instructions to change their behavior accordingly and to be able to protect their lives and the lives of their families against this epidemic. It has also been associated with many infodemic epidemics. Therefore, infodemic cannot be removed, but with appropriate solutions it can be managed to prevent the spread of misinformation (Tangcharoensathien et al. 2020). The devastating worldwide impact of COVID-19 can be attributed in part to the Infodemic associated with the disease.

Due to the epidemic of COVID-19 and the emergence of infodemic with this virus, researches have been done in this field. For example, Alvarez-Risco et al. (2020) examined the strategies implemented to control infodemic and believe that working with social media companies might provide a useful solution to the infodemic issue. Eysenbach (2020) stated four important pillars (i.e., supervising information, creating scientific literacy, encouraging the refinement of knowledge, and minimizing distorting factors and accurate and timely translation of knowledge) and believe that according to existence of social media, by supporting these pillars, infodemic can be controlled. Also, considering that COVID-19 has caused serious damage to most businesses, unprecedented health and economic disruptions in many countries (Alsalem et al. 2022). Hosseini et al. (2021) in this regard examined the problems of the ecotourism center and provided solutions to overcome these barriers, and then solutions were ranked based on four criteria (i.e., Time, cost, necessity, and Effectiveness). In addition, researchers have tried to find strategies for prevention and treatment COVID-19 by surveying Ayurveda practitioners. With analyzing the data, they concluded that not only social distancing is the most influential way to prevent the growth, but also, a possible diet and enhanced immune system can be used to combat COVID-19 (Panda et al. 2020).

Decision making is the process of choosing the greatest alternative from the obtainable alternatives. In real-world issues, we deal with more than one criterion in decision making, so multi-criteria decision making (MCDM) is formed (Haseli et al. 2020; Rahnamay Bonab and Osgooei 2022; Haseli and Sheikh 2022). MCDM methods have been broadly used in numerous fields (Ghoushchi et al. 2021a, b, c; Ghoushchi et al. 2019). In addition, MCDM is a good tool to help decision makers (DMs) recognize precedence strategies for evolving full disaster preparedness and response (Abikova 2020). A few numbers of studies demonstrated the utilization of MCDM methods on the subject of assessment of infectious disease epidemics and intervention strategies. Lately, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method has been used by Majumder et al. (2020) to choose important risk indicators and continual monitoring of COVID-19-induced death. Araz (2013) used Analytic Hierarchy Process (AHP) methodology to aid public health DMs to rank and assess effectual pandemic mitigation strategies. Chowdhury et al. (2022) presented an ensemble-based MCDM method for choosing highest performance machine learning technique for COVID-19. Samanlioglu (2019) provided AHP-VIKOR approach to assist multiple DMs to rank intervention influenza strategies. Pooripussarakul et al. (2016) applied the best–worst scaling method for vaccine immunization scheme in Thailand. AHP method has been utilized for risk evaluation of infectious diseases in china (Li et al. 2017; Tu et al. 2014).

Therefore, MCDM methods can be used to help governments determine the optimal program. DMs in decision making need to collect data from different sources and analyze information (Aydın and Kutlu Gündoğdu 2021; Rajabzadeh et al. 2022, Rajabzadeh and Babazadeh 2022). In many situations, DMs are unable to provide accurate values for evaluation. Hence, to manage the imprecision and ambiguities in MCDM, fuzzy set theory is used as an effective tool (Lin et al. 2021; Jafarzadeh Ghoushchi et al. 2022c; Albahri et al. 2022; Guo et al. 2020). Researchers have used MCDM methods by combining the concept of fuzzy theory in various fields. The Spherical fuzzy set (SFS) was established by Gündoğdu and Kahraman (2019), which is the generalized form of NS, IFS and PFS. By all means, it has greater space that gives greater latitudes to decision-makers. A linguistic assessment scale based on SFS gives the decision-makers the chance to make more reliable decisions and overcome their hesitancy (Gündoğdu and Kahraman 2020; Kutlu Gundogdu and Kahraman 2019). Due to the advantages of SFS, it has been used in many fields and MCDM methods have been developed in this set (Gündoğdu and Kahraman 2020; GÜNDOĞDU and Kahraman 2019; Gundogdu and Kahraman 2019; Kutlu Gündoğdu and Kahraman 2019a, b).

Infodemic causes confusion and high-risk behaviors that can be detrimental to health. It also leads to mistrust of health officials and weakens public health responses. With the growing digitalization of social media and the internet, information can spread even faster. This can help fill information gaps faster, but it can also reinforce harmful messages. Infodemic management is the systematic use of risk-based analysis and evidence-based approaches to infodemic management and the reduction of its impact on health behaviors in health emergencies. The existing literature shows that there is a need to consider and evaluate COVID-19 infodemic management strategies. This issue requires a systematic methodology and evaluation appropriate strategies. The process of selecting infodemic management strategies involves different subjective and objective criteria that have different goals. Therefore, this problem requires a systematic approach to evaluating strategies. Evaluating and selecting the best infodemic management strategy based on relevant criteria can help manage the epidemic and its consequences.

On the other hand, choosing the best strategy in the current situation to help the community and get rid of this epidemic is very important and vital. Because of the vitality of the issue COVID-19, the task of choosing the best strategy must be done correctly and carefully. To address this concern, an integrated BWM-CoCoSo approach has been developed for the first time in the SFS environment. This approach can effectively track the uncertainty and skepticism of DMs opinions in evaluating COVID-19 infodemic management strategies. The SFS environment allows DMs to define membership functions independently in a spherical area. Therefore, the ambiguity and uncertainty in the data is somewhat controlled and reduced. Also, using the BWM method, the number of even comparisons is reduced. The contributions of study are:

- Introduction a novel group decision support model under SFS integrated BWM-CoCoSo approach.
- Evaluate and select the most appropriate and best COVID-19 infodemic management strategy
- Comparison of the results obtained by the SFS-BWM-CoCoSo approach with other MCDM methods and previous fuzzy sets to indicate the reliability of the results.

This paper is organized into 5 sections. The preliminaries, including expressions of the concept of SFS, the SFS–BWM method, and the SFS-CoCoSo methods, are given in Sect. 2. The proposed framework is introduced in Sect. 3. Section 4 provides a case study and implementation of the proposed method to show its practicability and feasibility. In the last section, conclusions and future studies suggestions are presented.

2 Proposed methods

2.1 Preliminaries of spherical fuzzy sets

SFS in one of the newest fuzzy sets that has been introduced by Gündoğdu and Kahraman (2020). Some of the principles of SFS and their operation are explained in this section.

Definition 1 According to Gündoğdu and Kahraman (2020), an SPS T is as in Eq. (1).

$$\mathrm{T} = [(x \cdot (\mu_{\mathrm{T}}(x) \cdot v_{\mathrm{T}}(x) \cdot \pi_{\mathrm{T}}(x)))|x\epsilon \mathrm{X}] \tag{1}$$

In this relationship, $\mu_{\mathrm{T}} : \mathrm{X} \rightarrow [0.1].v_{\mathrm{T}} : \mathrm{X} \rightarrow [0.1].\pi_{\mathrm{T}} : \mathrm{X} \rightarrow [0.1]$ respectively illustrate the degrees of membership, non-membership, and hesitance degrees for every $x\epsilon\mathrm{X}$ in the SPS T, and the Eq. (2). Holds (Haseli and Jafarzadeh Ghoushchi 2022).

$$0 \leq (\mu_{\mathrm{T}}(x))^2 + (v_{\mathrm{T}}(x))^2 + (\pi_{\mathrm{T}}(x))^2 \leq 1 \tag{2}$$

Definition 2 (Zahid et al. 2022) Let $\mathrm{T1} = [\mu_{\mathrm{T1}} \cdot v_{\mathrm{T1}} \cdot \pi_{\mathrm{T1}}]$ and $\mathrm{T2} = [\mu_{\mathrm{T2}} \cdot v_{\mathrm{T2}} \cdot \pi_{\mathrm{T2}}]$ be two SFS numbers and $\mathcal{D} > 0$. So, the mathematical operations of these two SFS numbers are done via Eqs. (3) to (6).

$$T1 \oplus T2 = \left[\sqrt{\mu_{T1}^2 + \mu_{T2}^2 - \mu_{T1}^2\mu_{T2}^2} \cdot v_{T1}v_{T2} \cdot \sqrt{(1-\mu_{T2}^2)\pi_{T1} + (1-\mu_{T1}^2)\pi_{T2} - \pi_{T1}\pi_{T2}}\right] \tag{3}$$

$$T1 \otimes T2 = \left[\mu_{T1}\mu_{T2} \cdot \sqrt{v_{T1}^2 + v_{T2}^2 - v_{T1}^2 v_{T2}^2} \cdot \sqrt{(1-v_{T2}^2)\pi_{T1}^2 + (1-v_{T1}^2)\pi_{T2}^2 - \pi_{T1}^2\pi_{T2}^2}\right] \tag{4}$$

$$\mathcal{D}T = \left[\sqrt{1-(1-\mu_T^2)^{\mathcal{D}}} \cdot v_T^2 \cdot \sqrt{(1-\mu_T^2)^{\mathcal{D}} - (1-\mu_T^2-\pi_T^2)^{\mathcal{D}}}\right] \tag{5}$$

$$T^{\mathcal{D}} = \mu_T^{\mathcal{D}} \cdot \sqrt{1-(1-v_T^2)^{\mathcal{D}}} \cdot \sqrt{(1-v_T^2)^{\mathcal{D}} - (1-v_T^2-\pi_T^2)^{\mathcal{D}}} \tag{6}$$

Definition 3 (Jafarzadeh Ghoushchi et al. 2022a, b) Let $x = \{\mu_x \cdot v_x \cdot \pi_x\}$ represents the SFS number. The score value (SV) of the number T is computed as Eq. (7).

$$\mathrm{SV}(T) = (\mu_{xT} - \pi_T)^2 - (v_T - \pi_T)^2 \tag{7}$$

Note that: $T1 < T2$ if and only if

$$1.\ \mathrm{SV}\ (T1) < \mathrm{SV}\ (T2) \text{ or} \tag{8}$$

$$2.\ \mathrm{SV}\ (T1) = \mathrm{SV}\ (T2) \tag{9}$$

Sometimes the answers obtained through the score and accuracy are not appropriate and a negative or zero value may be obtained. As a result, the Prioritization Function (*PF*) is considered for SFS numbers, which is as Eq. (10).

$$\mathcal{PF}(x) = \mu_z * (1-v_x) * (1-\pi_x) \tag{10}$$

Definition 4 (Ghoushchi et al. 2021a, b, c) Given $w = (w_1 . w_2 . \ldots w_n). w_i\epsilon[0.1]; \sum_{i=1}^{n} w_i = 1,$ the spherical weighted arithmetic mean (SWAM) is computed as Eq. (11).

$$\left\{\begin{array}{l} \mathrm{SWAM}_w(x1 \ldots xn) = w_1 x1 + w_2 x2 + \ldots + w_n xn = \\ \left[1 - \prod_{i=1}^{n}(1-\mu_x^2)^{wi}\right]^{\frac{1}{2}} \cdot \prod_{i=1}^{n} v_x^{wi} \cdot \left[\prod_{i=1}^{n}(1-\mu_x^2)^{wi} - \prod_{i=1}^{n}(1-\mu_x^2-\pi_x^2)^{wi}\right]^{\frac{1}{2}} \end{array}\right\} \tag{11}$$

2.2 SFS–BWM method

The BWM method was introduced by Rezaei (2015). BWM is one of the newest and most efficient MCDM techniques used to weigh decision factors and criteria. the steps of the SFS- BWM are as follows:

Step 1 Determining a set of criteria by the expert team: In this step, the expert team specified and evaluates a set of criteria that affect the evaluation of options.

Step 2 Determining the best (most desirable or most important) and worst (least important) criteria among other criteria: The best and worst criteria should be determined among the criteria.

Step 3 Determining the preference of the best criterion over other criteria and other criteria over the worst criterion: The priority of the most significant criterion over the rest of the criteria is determined using Table 1. The SFS preference obtained from the best criterion overall criteria will be as follows.

$$(A_{\mathbb{B}})= ((\mu_{\mathbb{B}1},\ v_{\mathbb{B}1},\ \pi_{\mathbb{B}1}), (\mu_{\mathbb{B}2},\ v_{\mathbb{B}2},\ \pi_{\mathbb{B}2}), \ldots, (\mu_{\mathbb{B}n},\ v_{\mathbb{B}n},\ \pi_{\mathbb{B}n}) \tag{12}$$

Also, the SFS preference of all criteria over the worst criterion is determined using SFS numbers based on Table 2. The SFS preference obtained from all criteria over the worst criterion will be as Eq. (12).

$$(A_{\mathbb{W}}) = ((\mu_{1\mathbb{W}},\ v_{1\mathbb{W}},\ \pi_{1\mathbb{W}}), (\mu_{2\mathbb{W}},\ v_{2\mathbb{W}},\ \pi_{2\mathbb{W}}), \ldots, (\mu_{n\mathbb{W}},\ v_{n\mathbb{W}},\ \pi_{n\mathbb{W}})) \tag{13}$$

Step 4 Determining crisp value: In this step, the PF of all the expressed preferences is calculated using Eq. (13).

Step 5 Determine the optimal answer of weights and adaptation index.

A nonlinear programming model based on the elements obtained from the vectors $(A_{\mathbb{B}})$ and (A_W) is presented as Eq. (14).

Min ε

S.t

Table 1 Linguistic measures of importance used for pairwise comparisons

Linguistic variables	μ	v	π	CI
Extremely low (EL)	0.90	0.10	0.10	8
Very little (VL)	0.80	0.20	0.20	6
Little (L)	0.70	0.30	0.30	4
Middle little (ML)	0.60	0.40	0.40	2
Middle (M)	0.50	0.50	0.50	0
Middle high (MH)	0.40	0.60	0.40	0
Big (B)	0.30	0.70	0.30	0
Very tall (VT)	0.20	0.80	0.20	0
Tremendously high (TH)	0.10	0.90	0.10	0

Table 2 The list of criteria

Criteria		Type
Total estimated cost	C_1	Cost
Ease of implementation	C_2	Benefit
Approval by citizens	C_3	Benefit
Efficacy in preventing the expansion of COVID-19	C_4	Benefit
Irreplaceability by other measures	C_5	Cost
Time	C_6	Cost

$$\begin{cases} \left|\dfrac{W_{\mathbb{B}}}{W_j} - a_{\mathbb{B}j}\right| \le \varepsilon \\ \left|\dfrac{W_j}{W_{\mathbb{W}}} - a_{j\mathbb{W}}\right| \le \varepsilon \\ \sum_{j=1}^{n} W_j = 1 \\ W_j \ge 0 forallj \end{cases} \tag{14}$$

Equations (15) and (16) are used to calculate the compatibility index (*CI*) of SFS numbers in Table 1.

$$CI = \sqrt{|100 * ((\mu - \pi)^2 - (v - \pi)^2|} \tag{15}$$

For (AMI), (VHI), (HI), (SMI), and (EI).

$$\frac{1}{CI} = \frac{1}{\sqrt{|100 * ((\mu - \pi)^2 - (v - \pi)^2|}} \tag{16}$$

For (EI), (SLI), (LI), (VLI) and ALI.

Using the *CI* in Table 1, the value of the compatibility rate (*CR*) is calculated using Eq. (17),$CR < 0.1$ is acceptable.

$$CR = \frac{\varepsilon}{CI} \tag{17}$$

2.3 SFS-CoCoSo

For the first time, the Combined Compromised Solution (CoCoSo) method was proposed by Yazdani et al. (Yazdani et al. 2019) as a new MCDM method that combines simple additive weighting and exponentially weighted product model. In this study, CoCoSo is extended to SFS-CoCoSo, after specifying the alternatives and the related criteria, the steps of the proposed SFS- CoCoSo are as follows:

Step 1 Determination of the initial decision matrix:

The first step in MCDM methods is the construction of a decision matrix as shown below:

Let $D = \{d_1.d_2.\ldots.d_m\}$ be the set of choices, $C = \{C_1.C_2.\ldots.C_j.\ldots.C_n\}$ set of assumed criteria and $C = \{C_1.C_2.\ldots.C_j.\ldots.C_n\}$ set of weights with respect to

$w_j \in [0.1]$. Here X is the evaluation of choice M based on criteria n by decision-maker number K, which has been shown by $S = (S_{ij})_{m*n}$ matrix and it is formed on linguistic terms.

$$S = (C_j(d_i))_{m*n} = \begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \ddots & \vdots \\ S_{m1} & \cdots & S_{mn} \end{bmatrix} \quad (18)$$

Step 2 Linguistic variables Conversion into SFS numbers:

In the second step, the determined linguistic variables (LVs) from step 1 transform to SFS numbers using Table 2, and the decision matrix is built according to Eq. (19).

$$S = (C_j(d_i))_{m*n} = \begin{bmatrix} \{\mu_{11} \cdot v_{11} \cdot \pi_{11}\} & \cdots & \{\mu_{1n} \cdot v_{1n} \cdot \pi_{1n}\} \\ \vdots & \ddots & \vdots \\ \{\mu_{m1} \cdot v_{m1} \cdot \pi_{m1}\} & \cdots & \{\mu_{mn} \cdot v_{mn} \cdot \pi_{mn}\} \end{bmatrix} \quad (19)$$

Step 3 Aggregated Decision Matrix Construction:

In this step experts views are integrated considering the assigned weight for each. Afterward, the aggregated Decision matrix with the utilization of the Eq. (11).

Step 4 Calculation crisp values:

Using Eq. (10), *PF* value for each SFS number is calculated and the matrix of $S^* = \left(s^*_{ij}\right)_{m*n}$ is formed.

Step 5 Normalization of decision matrix.

In this step, with respect to the relations shown below, the decision matrix is normalized. Equation (20) for positive variables and Eq. (21) for negative variables. s_j^{*+} and s_j^{*-} are the highest and lowest values of each column of variables respectively.

$$\mathcal{S}\backslash S_{ij} = \begin{cases} \dfrac{s^*_{ij} - s_j^{*-}}{r_j^{+} - r_j^{-}} & if\ j \in B \\ \dfrac{s_j^{*+} - s^*_{ij}}{s_j^{*+} - s_j^{*-}} & if\ j \in C \end{cases} \quad (20)$$

$$where\ s_j^{*-} = \min_i s^*_{ij}\ and\ s_j^{*+} = \max_i s^*_{ij} \quad (21)$$

Step 6 Calculating the power weight of comparability and sum of weighted comparability sequences:

In this step, the power weight of comparability (P_i) and the sum of weighted comparability (S_i) sequences for each alternative are calculated. $\mathcal{W}_j$ is the weight of variables which is an input of CoCoSo method. S_i and P_i values are originated from the SAW and WASPAS methods, respectively.

$$P_i = \sum_{j=1}^{n} (\mathcal{S}_{ij})^{\mathcal{W}_j} \quad (22)$$

$$S_i = \sum_{j=1}^{n} \mathcal{W}_j * \mathcal{S}_{ij} \quad (23)$$

Step 7 Determination of appraisal score based on three strategies.

The score of the alternatives based on three appraisal strategies is obtained using Eqs. (24) to (26). Equation (24) defines the arithmetic mean of the scores of WSM and WPM while Eq. (25) expresses the relative scores of WSM and WPM compared to the best. Equation (26) is a balanced compromise of WSM and WPM. In Eq. (26), λ is assigned by an expert, although in the case of λ = 0.5 is more flexible.

$$k_{ia} = \frac{P_i + S_i}{\sum_{i=1}^{m} (P_i + S_i)} \quad (24)$$

$$k_{ib} = \frac{S_i}{\min_i S_i} + \frac{P_i}{\min_i P_i} \quad (25)$$

$$k_{ic} = \frac{\lambda S_i + (1-\lambda) P_i}{\lambda \max_i S_i + (1-\lambda) \max_i P_i} . 0 \le \lambda \le 1 \quad (26)$$

Step 8 Determination of final score and ranking of the options.

Based on Eq. (27) the final score is determined, in fact, it depicts the summation of arithmetic mean and Geometric mean of the previous three strategies, hence, the best options are with the higher k_i score.

$$k_i = \sqrt[3]{k_{ia} k_{ib} k_{ic}} + \frac{k_{ia} + k_{ib} + k_{ic}}{3} \quad (27)$$

2.4 Proposed approach phrases

This section presents the integrated BWM-CoCoSo approach in a SFS context to evaluate and rank COVID-19 infodemic management strategies using the accurate uncertainty measurement of SFS. The proposed approach is presented in two phases. First, the criteria identified and collected by experts are weighed using SFS–BWM. In this method, first the important and less important criteria are selected by experts and the rest of the criteria are differentiated to the best and worst criteria using Table 1. Then the mathematical linear model is constructed and solved and the weight of the criteria is obtained. In the second phase, the initial decision matrix is formed based on the experts opinions based on SFS–LVs. These values are transformed to SFS numbers utilizing Table 1, and strategies are prioritized according to the CoCoSo method. Unlike the traditional BWM and CoCoSo methods in SFS–BWM and SFS–CoCoSo, experts opinions are represented by SFS numbers, which contain the degree of membership and non-membership and the hesitance degree which are determine independently. Accordingly, the experts opinions are expressed without change or distortion. The suggested approach also displays more freedom to experts in their judgments and reduces decision uncertainty. Figure 3 illustrates how the proposed approach is implemented.

2.5 Context definition

We collected the data of six indicators for fifteen COVID-19 infodemic management strategies. The data is extracted from the experts who have valuable experience in infodemic management. The selected indicators include Total estimated cost, Ease of implementation, Acceptability to citizens, Effectiveness in preventing the spread of COVID-19, Irreplaceability by other measures, and Time are considered two types include cost and benefit. The different types of indicators and are defined in Table 2.

In the following, a brief description about COVID-19 infodemic management strategies that evaluated and prioritized in this paper are shown in Table 3.

3 Results and discussion

3.1 Implementing the proposed approach

In this section, the results of the proposed approach for evaluating executive strategies against infodemic COVID-19 based on selected criteria are examined. According to the explanations provided in the proposed approach, for weighting criteria using the SFS–BWM method, experts first determine the most important and insignificant criteria. C2 has been selected as the best criterion and C5 as the worst criterion by experts. It can be seen in Table 4, the outputs of pairwise comparisons of the best criterion over the other criteria as well as the other criteria over the worst criterion using the LVs mentioned in Table 2.

The SFS best-to-others and others-to-worst criteria vectors are shown based on Tables 4 and 5 as follows:

$(\mathcal{A}_{\mathbb{B}})^P = ((0.8,\ 0.2,\ 0.2),\ (0.7,\ 0.3,\ 0.3),\ (0.6,\ 0.4,\ 0.4),\ (0.9,\ 0.1,\ 0.1),\ (0.7,\ 0.3,\ 0.3))$

$(\mathcal{A}_{\mathbb{W}})^P = ((0.6,\ 0.4,\ 0.4),\ (0.9,\ 0.1,\ 0.1),\ (0.7,\ 0.3,\ 0.3),\ (0.8,\ 0.2,\ 0.2),\ (0.6,\ 0.4,\ 0.4))$

Then the LVs expressed by the specialists are converted to SFS numbers using Table 1. Finally, the crisp values of SFS numbers are obtained using Eq. (10) and the nonlinear programming model is written based on Eq. (14). By solving the written nonlinear model, the final weights of the criteria are calculated which can be seen in Table 6.

The SF-CoCoSo method is then used to rank strategies. According to this methods first step, the decision matrix is first formed by the experts with SFS–LVs. So, the rows of

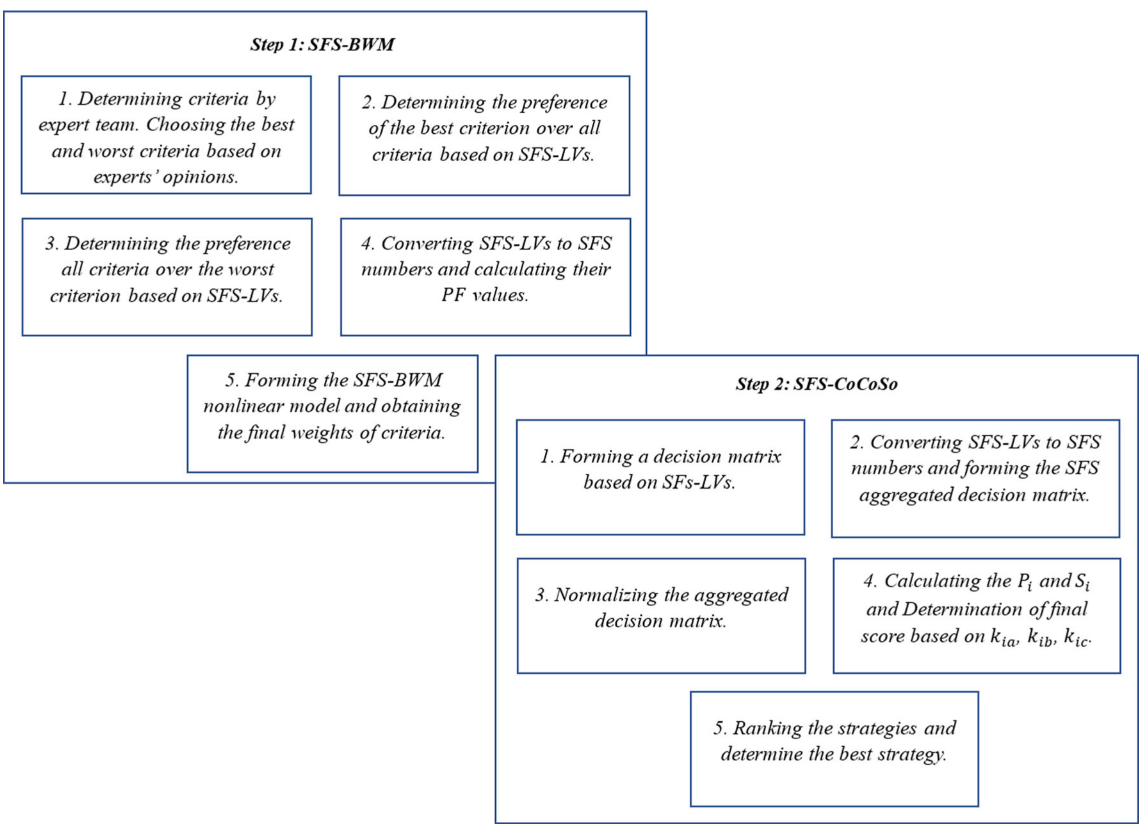

Fig. 3 Flowchart of the proposed methodology

Table 3 Evaluated strategies and related descriptions

Strategies		Description
Timely health information tailored for specific audiences	S1	Posting short and animated videos is usually between 30 s and 2 min or less on official virtual media
COVID-19 posters and infographics	S2	Creating a number of posters of concepts such as diagnosis, transmissibility, pandemic initiation and health measures
Promote resilience to misinformation	S3	Holding training courses. This course includes a range of infodemic management skills to apply interventions for resilience of individuals against infodemic
COVID-19 questions and answers (Q&As)	S4	Updating questions and answers related to COVID-19 constantly, until the latest science is available to the public
Coronavirus disease advice for the public: MythBusters	S5	Creating a page containing WHO recommendations on ways to prevent the spread of COVID-19
Online tools for fact checking COVID-19 information	S6	Establishing COVID-19 Fact-Finding Center, an international body consisting of active COVID-19 fact-finding teams
Videos: Dos and donts series	S7	Sharing step-by-step instructions via video and posters on what to do and what not to do
Creating the science	S8	Inviting specialists from around the world in many fields to advance infodemiology
Influential partnerships in action, seeking to empower key leaders across society	S9	Designing an information ecosystem, using trusted channels to exchange information
Collective Service newsletters	S10	Creating multiple stakeholder groups in communities to build trust, social cohesion to reduce transmission
Collective Service partnership	S11	Creating weekly newsletters that aim to provide insights and updates on exciting research from around the world
COVID-19 weekly operational update	S12	COVID-19 Weekly Operational Updating
COVID-19 EPI-WIN updates	S13	Timely and accurate information updates on a wide range of topics related to COVID-19
Media interviews	S14	Establishing active dialogue with key stakeholders and group discussions on infodemic management
Engage and empower communities	S15	Community participation including counseling, information as well as engaging and collaborating with different communities in different cultures and geographies

Table 4 SFS pairwise comparisons of best-to-other criteria

Criteria	C_1	C_3	C_4	C_5	C_6
Best criterion (C_2)	(0.8, 0.2, 0.2)	(0.7, 0.3, 0.3)	(0.6, 0.4, 0.4)	(0.9, 0.1, 0.1)	(0.7, 0.3, 0.3)

Table 5 SFS pairwise comparisons of other-to-worst criterion

Criteria	Worst criterion(C5)
C_1	(0.6, 0.4, 0.4)
C_2	(0.9, 0.1, 0.1)
C_3	(0.7, 0.3, 0.3)
C_4	(0.8, 0.2, 0.2)
C_6	(0.6, 0.4, 0.4)

this matrix represent the strategies against infodemic COVID-19 and the columns of this matrix represent the evaluation criteria (see Table 7).

Then, according to the Table 1, the expressed language variables are converted into SFS numbers. And according to step (3), the aggregated matrix is formed based on the weight of the experts and using Eq. (11).

In the next step, the crisp values of SFS numbers are obtained based on Eq. (10) and the normalized matrix is formed based on Eqs. (20) and (21). After normalizing the decision matrix, using the weights obtained from the SFS–BWM method, the power weight of comparability (P_i) and the sum of weighted comparability (S_i) sequences are calculated. Finally, k_{ia}, k_{ib} and k_{ic} are calculated using Eqs. (24) to (26). In this equation, the value of λ for equilibrium is considered equal to 0.5. And using these 3 values, the final score of each strategy, k_i based on Eq. (27) is obtained. According to the Table 8, we find that S6 with a score of 2.448 has a higher priority than other strategies. Hence, based on this prioritization, specialists can focus on these strategies to deal with infodemic COVID-19.

3.2 Sensitivity analysis

In this section, sensitivity analysis has also been performed to assess the stability of the obtained results. In the

Table 6 Final weigth of the criteria

Criteria	weight	Priority
Total estimated cost (C_1)	0.082	4
Ease of implementation (C_2)	0.420	1
Acceptability to citizens (C_3)	0.122	3
Effectiveness in preventing the spread of COVID-19 (C_4)	0.194	2
Irreplaceability by other measures (C_5)	0.057	5
Time (C_6)	0.122	3

Table 7 The decision matrix in form of SFS-LVs

Strategies	C_1			C_2			C_3		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
S1	VL	L	M	M	VL	M	L	VL	L
S2	M	VL	M	VL	VL	L	M	L	M
S3	L	M	VL	M	L	M	VL	L	VL
S4	L	L	VL	M	L	L	M	VL	L
S5	VL	L	L	VL	VL	M	MH	M	M
S6	VL	L	L	L	VL	VL	L	VL	L
S7	VL	L	VL	L	M	M	VL	VL	L
S8	L	L	M	VL	L	VL	VL	M	L
S9	L	M	M	L	L	VL	M	L	VL
S10	L	VL	L	L	M	VL	M	M	L
S11	L	M	L	M	L	VL	VL	L	VL
S12	M	L	M	VL	VL	L	VL	L	VL
S13	L	M	L	VL	L	VL	M	L	M
S14	VL	L	VL	M	VL	L	M	L	L
S15	L	M	M	VL	L	VL	VL	L	VL

Strategies	C_4			C_5			C_6		
	DM1	DM2	DM3	DM1	DM2	DM3	DM1	DM2	DM3
S1	L	M	M	M	M	M	VL	L	VL
S2	M	L	M	VL	VL	M	M	VL	L
S3	L	L	VL	M	L	L	MH	M	M
S4	L	VL	VL	L	VL	L	L	VL	L
S5	VL	M	L	L	VL	VL	L	L	M
S6	VL	L	VL	VL	L	L	L	M	M
S7	L	L	VL	L	M	VL	L	VL	VL
S8	L	M	M	M	L	L	L	VL	L
S9	L	L	M	M	L	L	VL	L	VL
S10	L	M	L	VL	M	L	VL	L	VL
S11	M	M	L	M	M	M	L	M	M
S12	M	L	M	L	VL	M	L	M	VL
S13	L	M	M	L	VL	L	VL	L	VL
S14	L	VL	VL	L	VL	VL	M	VL	L
S15	L	VL	L	L	M	VL	VL	L	VL

Table 8 The results from the CoCoSo method

Strategies	S_i	p_i	K_{ia}	K_{ib}	K_{ic}	K_i	Rank
S1	0.315	4.098	0.058	2.186	0.684	1.417	14
S2	0.577	5.115	0.074	3.315	0.882	2.025	5
S3	0.454	4.844	0.069	2.843	0.821	1.789	7
S4	0.394	5.056	0.071	2.711	0.845	1.755	10
S5	0.530	3.615	0.054	2.735	0.643	1.600	11
S6	0.788	5.664	0.084	4.147	1.000	2.448	1
S7	0.312	3.879	0.055	2.113	0.650	1.361	15
S8	0.625	5.328	0.078	3.530	0.923	2.143	4
S9	0.502	4.486	0.065	2.895	0.773	1.771	9
S10	0.321	4.172	0.059	2.225	0.696	1.443	13
S11	0.490	4.612	0.067	2.893	0.791	1.784	8
S12	0.683	5.336	0.078	3.718	0.933	2.225	3
S13	0.547	4.361	0.064	3.001	0.761	1.802	6
S14	0.463	3.484	0.051	2.482	0.612	1.476	12
S15	0.772	4.863	0.073	3.866	0.873	2.233	2

proposed approach, the final ranking is based on the λ parameter, which originates from the CoCoSo method. In this section, by changing the λ parameter, we examine its effect on the ranking results. Several scenarios have been defined for this purpose. Figure 4 shows the different λ values and ranking results. Based on the results, we find that with the change of λ, there is no fundamental change in the results. The ranking is the same in all scenarios, and λ change does not have a serious impact on the ranking because S in all scenarios it is identified with high priority. However, depending on the nature of the data and the subject matter, experts, can make serious decisions about the value of λ. From the comparison of the results, it can be seen that the advanced model is stable. Hence, the results obtained from the initial results can be accepted as the final ranking. However, experts can make a serious decision about the amount of λ, depending on the nature of the data and the issue.

3.3 Comparative analysis

CoCoSo is a new MCDM method that combines simple additive weighting and exponentially weighted product model. It is one of the recent multi-criteria decision-making methods based on compromise solutions and a useful technique in ranking or selecting multiple alternatives. The purpose of this section is to compare the ranking of companies in different methods of MCDM. To show the capability of the proposed method and the validation of the obtained results, the ranking has been done with other MCDM methods, such as Multi-Objective Optimization on the basis of the Ratio Analysis (MOORA), The complex Proportional Assessment (COPRAS), and the Measurement of Alternatives and Ranking according to the Compromise Solution (MARCOS) in a SFS environment. In this case study, we compared the SFS–CoCoSo method with MCDM models that have a linear normalization. We calculated a spearman rank correlation coefficient between the ranking results of the proposed approach and SF-MARCOS as a reliable method (Jafarzadeh Ghoushchi et al. 2022c; Memarpour Ghiaciet al. 2022). The coefficient is observed as 0.964. Also, the correlation coefficients between the proposed approach of this study and SF-COPRAS (Omerali and Kaya 2022) and SF-MOORA (Jafarzdeh Ghoushchi et al. 2022a) are both 0.878. Figure 5 shows the results of the CoCoSo

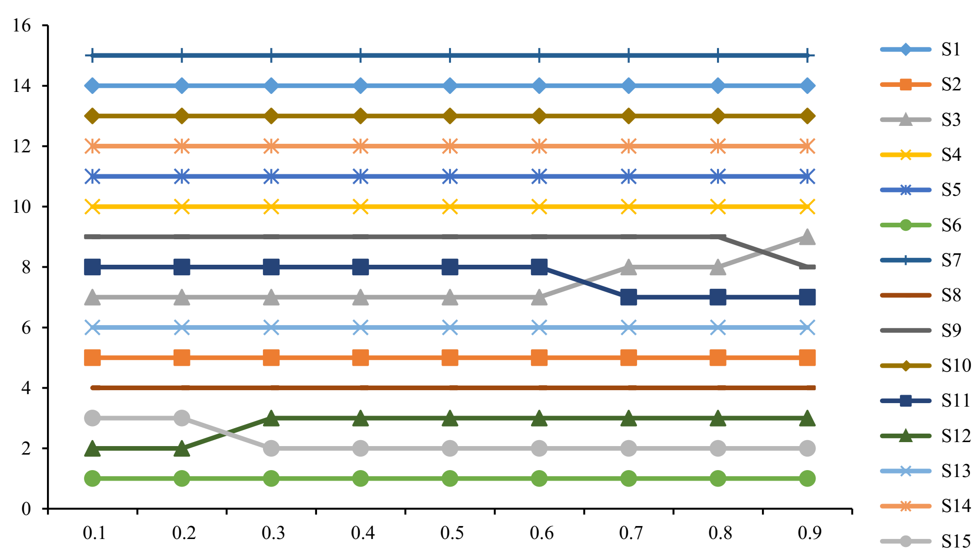

Fig. 4 Comparison of failure mode rankings with different λ

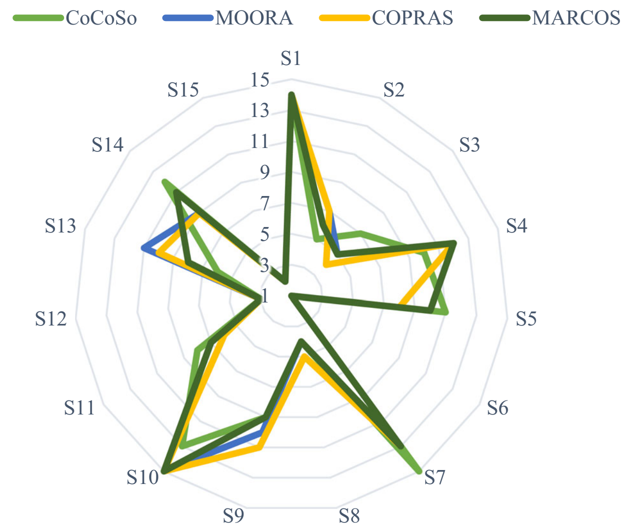

Fig. 5 Comparison of ranking strategies based on SFS

method and other mentioned MCDM methods to select the best strategy. According to the results of the CoCoSo, in terms of choosing the best strategy, it is completely correlated with other methods. In all methods, S6 has been selected as the superior strategy. According to the Fig. 5 comparison of the ranking results shows that the results obtained from the SFS–CoCoSo method are acceptable and reliable.

4 Conclusions

Infodemic refers to a situation in which a large amount of information is generated about a problem, and this breadth of information makes it complex to discover a solution. Dissemination of inaccurate information and statements hinders the response to effective health strategies and causes uncertainty, stress and anxiety among people. Infectious disease epidemics will continue to occur and require flexible multidisciplinary hospitalizations for infodemic management, which is stable between disease outbreaks and is the mainstay of any response. Poor and uncoordinated management of infodemics may lead to unintended outcomes such as marginalization and suppression of science in the interests of commercial and political interests. The proposed strategies with the aim of infodemic management can emphasize the creation and dissemination of valid health information, elimination of incorrect and harmful information, increase the resilience and flexibility of individuals and communities against incorrect information.

In this paper, an integrated approach has been developed based on SFS–BWM and SFS–CoCoSo methods for evaluating COVID-19 infodemic management strategies are proposed. In this study, to rank COVID-19 infodemic management strategies, 6 effective criteria were identified and weighed by the SFS–BWM method. BWM is one of the latest and most powerful MCDM methods for weighting the criteria. The COVID-19 infodemic management strategies are then ranked using the SFS–CoCoSo method. The results showed that S6 and S15 are selected as best strategies for management infodemic. Given the ambiguity of information in the real-world MCDM process and the uncertainty in the DMs qualitative judgments, crisp values cannot cover this insufficient information. The SFS includes the degrees of membership, non-membership, and hesitancy which are defined independently. SFS increases the preference of DMs and reduces uncertainty and leads to more reliable and accurate results. Also, the comparison of the proposed approach with other MCDM methods (i.e., MOORA, COPRAS, and MARCOS) showed that the ranking results of the proposed approach are reliable. It is also shown that the parameter changes λ based on the proposed SFS–CoCoSo method has no significant effect on the ranking and S6 has been selected as the best strategy in all scenarios. The main purpose of this paper is to help policy makers, health services, governments, experts and implementers.

This paper, like other papers, is not without its limitations. One of the main limitations of this paper is the relationship between criteria that has not been considered. In the real world, there are usually relationships and interactions between criteria that may affect the ranking of alternatives. Another limitation of this paper is the SFS–LVs used in the proposed approach, which are in the form of 9 scales. Probably by increasing the scale of LVs, experts will be able to present their opinions with a greater degree of freedom. On the other hand, in this paper, the experience and expertise of three experts has been used to collect data and information needed to review strategies. It is possible that the ranking results will change somewhat by increasing the number of experts or taking advantage of the opinions of other experts.

In future research, it is suggested that more experts in this field be used to collect data and obtain more accurate and reliable results. Choquet integral or fuzzy cognitive map can also be used to examine the relationships between the criteria for accurate results. In addition, two fuzzy numbers can be used to increase the confidence in the opinions of experts. Therefore, the proposed approach can be developed with Z-number and D-number theories to reduce the uncertainty in the opinions of experts.

Appendix

See Tables 9, 10 and 11.

Table 9 The aggregated SFS decision matrix

Strategies	C_1	C_2	C_3	C_4	C_5	C_6
S1	(0.70, 0.29, 0.31)	(0.67, 0.32, 0.33)	(0.73, 0.26, 0.26)	(0.62, 0.38, 0.39)	(0.54, 0.45, 0.46)	(0.77, 0.22, 0.22)
S2	(0.65, 0.34, 0.36)	(0.77, 0.22, 0.22)	(0.61, 0.39, 0.39)	(0.61, 0.39, 0.40)	(0.75, 0.24, 0.25)	(0.70, 0.29, 0.29)
S3	(0.71, 0.28, 0.29)	(0.63, 0.36, 0.36)	(0.77, 0.22, 0.22)	(0.73, 0.26, 0.26)	(0.66, 0.33, 0.33)	(0.50, 0.50, 0.50)
S4	(0.73, 0.26, 0.26)	(0.66, 0.33, 0.33)	(0.70, 0.29, 0.29)	(0.76, 0.23, 0.23)	(0.73, 0.26, 0.26)	(0.73, 0.26, 0.26)
S5	(0.74, 0.25, 0.25)	(0.75, 0.24, 0.25)	(0.50, 0.50, 0.50)	(0.70, 0.29, 0.31)	(0.76, 0.23, 0.23)	(0.65, 0.34, 0.34)
S6	(0.74, 0.25, 0.25)	(0.76, 0.23, 0.23)	(0.73, 0.26, 0.26)	(0.77, 0.22, 0.22)	(0.74, 0.25, 0.25)	(0.62, 0.38, 0.38)
S7	(0.77, 0.22, 0.22)	(0.64, 0.35, 0.35)	(0.77, 0.22, 0.22)	(0.73, 0.26, 0.26)	(0.71, 0.28, 0.29)	(0.76, 0.23, 0.23)
S8	(0.67, 0.32, 0.32)	(0.77, 0.22, 0.22)	(0.70, 0.29, 0.29)	(0.62, 0.38, 0.39)	(0.66, 0.33, 0.33)	(0.73, 0.26, 0.26)
S9	(0.62, 0.38, 0.39)	(0.73, 0.26, 0.26)	(0.68, 0.32, 0.32)	(0.65, 0.34, 0.36)	(0.66, 0.33, 0.33)	(0.77, 0.22, 0.22)
S10	(0.73, 0.26, 0.26)	(0.71, 0.28, 0.29)	(0.61, 0.39, 0.39)	(0.65, 0.34, 0.36)	(0.72, 0.27, 0.28)	(0.77, 0.22, 0.22)
S11	(0.67, 0.32, 0.32)	(0.70, 0.29, 0.30)	(0.77, 0.22, 0.22)	(0.60, 0.40, 0.41)	(0.53, 0.46, 0.47)	(0.64, 0.35, 0.35)
S12	(0.63, 0.36, 0.36)	(0.77, 0.22, 0.22)	(0.77, 0.22, 0.22)	(0.61, 0.39, 0.40)	(0.71, 0.28, 0.29)	(0.71, 0.28, 0.28)
S13	(0.65, 0.34, 0.36)	(0.77, 0.22, 0.22)	(0.61, 0.39, 0.39)	(0.62, 0.38, 0.39)	(0.73, 0.26, 0.26)	(0.77, 0.22, 0.22)
S14	(0.77, 0.22, 0.22)	(0.70, 0.29, 0.30)	(0.66, 0.33, 0.33)	(0.76, 0.23, 0.23)	(0.76, 0.23, 0.23)	(0.70, 0.29, 0.29)
S15	(0.64, 0.35, 0.35)	(0.77, 0.22, 0.22)	(0.77, 0.22, 0.22)	(0.73, 0.26, 0.26)	(0.71, 0.28, 0.29)	(0.77, 0.22, 0.22)

Table 10 The normalized decision matrix

Strategies	C_1	C_2	C_3	C_4	C_5	C_6
S1	0.540	0.244	0.790	0.088	0.970	0.000
S2	0.834	1.000	0.255	0.039	0.076	0.373
S3	0.470	0.000	1.000	0.729	0.524	1.000
S4	0.297	0.182	0.627	0.933	0.173	0.210
S5	0.222	0.813	0.000	0.507	0.000	0.592
S6	0.222	0.920	0.790	1.000	0.115	0.708
S7	0.000	0.060	1.000	0.729	0.306	0.052
S8	0.696	1.000	0.618	0.088	0.524	0.210
S9	1.000	0.677	0.493	0.237	0.524	0.000
S10	0.297	0.489	0.255	0.237	0.248	0.000
S11	0.696	0.427	1.000	0.000	1.000	0.612
S12	0.920	1.000	1.000	0.039	0.306	0.332
S13	0.837	1.000	0.255	0.088	0.173	0.000
S14	0.000	0.427	0.467	0.933	0.000	0.373
S15	0.865	1.000	1.000	0.729	0.306	0.000

Table 11 Comparison of CoCoSo method ranking with other MCDM methods

Strategies	SFS-CoCoSo		SFS-MOORA		SFS-COPRAS		SFS-MARCOS	
	Score	Rank	Score	Rank	Score (%)	Rank	Score	Rank
S1	1.417	14	0.024	14	73.7	14	0.571	14
S2	2.025	5	0.032	7	83.7	7	0.650	6
S3	1.789	7	0.033	5	88.9	4	0.659	5
S4	1.755	10	0.028	12	79.5	12	0.598	12
S5	1.600	11	0.031	8	82.4	8	0.632	10
S6	2.448	1	0.044	1	100.0	1	0.769	1
S7	1.361	15	0.025	13	76.5	13	0.577	13
S8	2.143	4	0.035	4	87.5	5	0.679	4
S9	1.771	9	0.030	10	81.4	11	0.639	9
S10	1.443	13	0.022	15	71.8	15	0.551	15
S11	1.784	8	0.032	6	86.8	6	0.645	7
S12	2.225	3	0.038	3	91.9	3	0.715	3
S13	1.802	6	0.030	11	81.5	10	0.645	8
S14	1.476	12	0.030	9	82.3	9	0.625	11
S15	2.233	2	0.042	2	97.5	2	0.767	2

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Declarations

Conflict of interest Conflicts of interest authors declare that either of them has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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