



# A Multi-Criteria Decision-Making Model with Interval-Valued Intuitionistic Fuzzy Sets for Evaluating Digital Technology Strategies in COVID-19 Pandemic Under Uncertainty

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## Abstract

Coronavirus diseases 2019 (COVID-19) pandemic is an essential challenge to the health and safety of people, medical members, and treatment systems worldwide. Digital technologies (DTs) have been universally introduced to improve the treatment of patients during the pandemic. Nevertheless, only a few governments have been partly successful in executing the DT strategies. In this regard, it is critical to demonstrate a suitable strategy for the governments. This problem is built based on the experts' opinions with some conflicting criteria to evaluate various types of alternatives. Hence, this research presents a new multi-criteria decision-making (MCDM) model under uncertain conditions. For this reason, interval-valued intuitionistic fuzzy sets (IVIFSs) are employed to help decision-makers (DMs) evaluate in a broader area and cope with uncertain information. Moreover, a new extended weighting method based on weighted distance-based approximation (WDBA) and a new combined ranking approach are proposed to determine the DMs' weights and rank the alternatives under IVIF conditions. The developed weighting method is constructed based on computing the DMs' weights with objective criteria weights. Furthermore, a new ranking approach is proposed by obtaining two ranking indexes separately: The first and second ranking indexes are calculated according to the positive and negative ideal solutions distances and the nature of criteria weights, respectively. Afterward, the final values of rankings are computed by considering a new aggregating procedure. The results of the proposed model represent the first alternative as the best strategy. Comparisons between the IVIF-TOPSIS and IVIF-VIKOR methods are also provided to investigate the proposed model to determine the rankings of main alternatives. Sensitivity analyses are conducted to check the reliability and the robustness of the model. For this purpose, criteria weights are analyzed to compute the dependencies' degree of the new extended weighting method. The dependencies of the ranking model are discussed on the criteria weights as well.

**Keywords** Coronavirus disease 2019 (COVID19) · Digital technology · Digital technology strategies · Multi-criteria decision making · WDBA method · Interval-valued intuitionistic fuzzy sets

## 1 Introduction

Coronavirus disease 2019 (COVID-19), made with a new kind of coronavirus SARS-CoV-2, was first identified in December 2019 as a case of pneumonia in Wuhan, China which has become a global pandemic, afterward [1]. World Health Organization (WHO) advertised the outbreak of a pandemic on March 11 and asked for conjunction procedures to support readiness and quick answer to the infection

across the world's health parts [2]. COVID-19 is one of the most infectious diseases in the decades for which various approaches and technologies have been introduced to support the treatment, handling, and control of the pandemic. For this reason, governments and health organizations make efforts to handle the expansion of coronavirus; they need all the help from digital technology (DT).

During the COVID-19 pandemic, digital health-based applications may significantly support associations and societies. DTs can also be used for stopping and observing measures, for example, through applications of tracing or monitoring internet searches and social media usage [3, 4]. Hence, diverse models and technologies are proposed to support the cure and control of the pandemic, including robotics

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and healthcare artificial intelligence (AI) applications [5, 6]. The AI technologies can be used following COVID-19 outbreak for informing patients, disinfecting areas, as well as speeding up the search for effective treatments [7]. Furthermore, executed applications have been examined and evaluated from the viewpoint of technologies, potentially missing how policy directives contributed to the formulation of digital health landscape for COVID-19 [8]. In this way, Ting et al. [9] analyzed the DT in healthcare industry to handle the problematic position of the COVID-19 in four steps.

Meanwhile, DT selection for the healthcare industry in the COVID-19 pandemic application can be distinguished as a type of multiple criteria decision-making (MCDM) problem [10]. In addition, one of the effective methods applied in MCDM problems is the weighted distance-based approximation (WDBA) approach which has the same concept of the technique for order of preference by similarity to the ideal solution (TOPSIS) method and is categorized in the field of compromise solution approaches. As the WDBA method includes simple formulations and is straightforward, it is better than TOPSIS [11]. The WDBA technique has been successfully applied for selection processes in many MCDM problems [12]. In this regard, many researchers have begun to present new approaches to the MCDM for the DT selection of high uncertainty in pandemic and disease conditions based on uncertain linguistic terms [13]. However, the fuzzy sets (FSs) theory suggested by Zadeh in [14] has achieved great success in different fields. Meanwhile, intuitionistic fuzzy sets (IFSs) proposed by Atanassov [15] have been established to be very beneficial in dealing with vagueness. Generally, IFS examines the membership and non-membership of an element to a given set whose values are described between 0 and 1 [16]. The comparison between the mentioned approach and the initial FSs represents the IFS as the more experimental method in handling vagueness. Therefore, decision-makers (DMs) use IFSs to better demonstrate information under uncertain conditions [17, 18].

Due to the increasing complexity of the problem conditions, the lack of problem knowledge, and the limited ability of DMs relevant to the information process, it is hard to precisely describe DMs' priorities by focusing on criteria. However, it is possible to express them as a value range. In other words, to assess a criterion, DMs may be more comfortable expressing the value of the index with satisfactory and dissatisfactory degrees using an interval value. Eventually, the IFSs under interval conditions are changed to interval-valued intuitionistic fuzzy sets (IVIFSs) [19]. The IFSs and IVIFSs have received attention in recent years, and several kinds of research have been conducted to develop and modify their theories.

Ecer and Pamucar [20] extended the MACROS technique under the IF environment to measure the performance of the

insurance companies during the COVID-19 outbreak. Goker [21] proposed an integrated agile IF decision in the COVID-19 pandemic condition for a provider selection. Hezam et al. [22] presented the neutrosophic MCDM approach for the COVID-19 vaccination decision-making process. Alkan and Kahreman [23] introduced the q-rung orthopedic fuzzy TOPSIS method to select an appropriate government strategy during the COVID-19 pandemic. Narayanamoorthy et al. [24] evaluated the vaccination of Youngsters in the COVID-19 pandemic condition by PROMETHEE-II in an IF environment. Tumsekcali et al. [25] proposed an IVIF-based methodology during the COVID-19 pandemic. Zhang and Huang [26] provided the Z-IF MULTIMOORA method with the AHP approach in a real-case study of COVID-19. Boyaci and Sisman [27] suggested the selection site of the hospital in the COVID-19 pandemic condition in which Pythagorean fuzzy sets have been employed to cope with uncertain conditions. Mardani et al. [28] proposed a hesitant fuzzy MCDM technique for the selection of healthcare technology in the COVID-19 outbreak.

Saraji et al. [29] offered the MCDM problem to select suitable education techniques under hesitant fuzzy sets. Alkan and Kahraman [30] introduced IF-TOPSIS method to choose the hospital site under pandemic conditions. Chen and Lin [31] proposed an FGM decomposition-MCDM method based on FSs for selecting the smart technology tools to support mobile healthcare during and after the COVID-19 pandemic. De Andrade et al. [32] introduced an integrated MCDM method to evaluate the impact of COVID-19 on social welfare regarding the utility of food apps. Ali et al. [33] presented a hybrid MCDM approach to assess the COVID-19 pandemic on future energy systems in developing countries. Nguyen et al. [34] proposed an integrated MCDM method to evaluate financial impacts of the COVID-19 on banking and commercial policies. Toan et al. [35] presented a two-stage grey MCDM approach to select video conference software during the COVID-19 pandemic.

According to the clarification, MCDM studies on the COVID-19 pandemic respecting uncertain conditions are limited in the literature. The literature review indicates that the decision-making approaches are far from the real-world applications and do not consider them in uncertain situations. Furthermore, all the previous related works do not focus on the experts' weights, although their opinions have an important impact on making appropriate decisions. Besides, the determination of ranking values by considering two separate ranking methods have received less attention from the studies. Accordingly, this paper proposes a new integrated IVIF-decision-making model to compute the DMs' weights with a new extended weighting method. Also, a new hybrid ranking approach is developed by considering two ranking indexes to calculate the final ranking of the alternatives and make an appropriate decision. For this reason, the weights

expressed by DMs are computed based on a new version of the WDBA method consisting of the average, negative, and positive ideal solutions under IVIF conditions. Afterward, a new combined ranking approach is proposed based on the distance between negative and positive ideal solutions. The main innovations of the paper are explained below:

- Introducing a new multi-criteria decision-making model with IVIF for evaluating DT strategies under the COVID-19 pandemic.
- Presenting a new extended weighting method to compute weights of DMs.
- Proposing a new combined method to rank the alternatives.
- Applying the empirical example in the COVID-19 pandemic environment.

The rest of the paper is organized as follows. Section 2 develops the preliminaries and the basic description; Sect. 3 presents the proposed method; Sect. 4 extends the empirical example; Sect. 5 provides the sensitivity analysis. Finally, Sect. 6 presents the conclusions and further research suggestions.

## 2 Preliminaries

This section examines the basic definitions of the IVIFS. These definitions are determined below:

**Definition 1 [36]** Let  $U = \{u_1, u_2, \dots, u_n\}$  be a universe. An IVIFS  $\tilde{S}$  in  $U$  is described by Eq. (1).

$$\tilde{S} = \{u_i, \mu_{\tilde{S}}(u_i), v_{\tilde{S}}(u_i) | u_i \in U\} \tag{1}$$

where  $\mu_{\tilde{S}}(u_i) = [\mu_{\tilde{S}}^l(u_i), \mu_{\tilde{S}}^u(u_i)]$ ,  $v_{\tilde{S}}(u_i) = [v_{\tilde{S}}^l(u_i), v_{\tilde{S}}^u(u_i)]$  and  $\mu_{\tilde{S}}(u_i), v_{\tilde{S}}(u_i) \in [0, 1]$ . In these forms,  $\mu_{\tilde{S}}^l(u_i)$  is the infimum of the  $\mu_{\tilde{S}}(u_i)$  and  $\mu_{\tilde{S}}^u(u_i)$  is the supremum of the  $\mu_{\tilde{S}}(u_i)$ . This condition also applies to  $v_{\tilde{S}}(u_i)$  simultaneously.

$$\mu_{\tilde{S}}^u(u_i) + v_{\tilde{S}}^u(u_i) \leq 1 \quad \forall u_i \in U \tag{2}$$

$$\pi_{\tilde{S}}(u_i) = [\pi_{\tilde{S}}^l(u_i), \pi_{\tilde{S}}^u(u_i)] \tag{3}$$

where  $\pi_{\tilde{S}}^l(u_i) = 1 - \mu_{\tilde{S}}^u(u_i) - v_{\tilde{S}}^u(u_i)$  and  $\pi_{\tilde{S}}^u(u_i) = 1 - \mu_{\tilde{S}}^l(u_i) - v_{\tilde{S}}^l(u_i)$  for  $u_i \in U$ . Also, if  $\mu_{\tilde{S}}(u_i) = \mu_{\tilde{S}}^u(u_i) = \mu_{\tilde{S}}^l(u_i)$  and  $v_{\tilde{S}}(u_i) = v_{\tilde{S}}^u(u_i) = v_{\tilde{S}}^l(u_i)$ , the IVFS changes to the IFS.

**Definition 2 [37]** Let  $\tilde{R}_1 = ([\mu_{\tilde{R}_1}^l, \mu_{\tilde{R}_1}^u], [v_{\tilde{R}_1}^l, v_{\tilde{R}_1}^u])$ ,  $\tilde{R}_2 = ([\mu_{\tilde{R}_2}^l, \mu_{\tilde{R}_2}^u], [v_{\tilde{R}_2}^l, v_{\tilde{R}_2}^u])$ ,  $\tilde{R} = [\mu_{\tilde{R}}^l, \mu_{\tilde{R}}^u], [v_{\tilde{R}}^l, v_{\tilde{R}}^u]$ . The mathematical operations are shown in Eqs. (4)–(7).

$$\begin{aligned} &\tilde{R}_1 \oplus \tilde{R}_2 \\ &= ([\mu_{\tilde{R}_1}^l + \mu_{\tilde{R}_2}^l - \mu_{\tilde{R}_1}^l \mu_{\tilde{R}_2}^l, \mu_{\tilde{R}_1}^u + \mu_{\tilde{R}_2}^u - \mu_{\tilde{R}_1}^u \mu_{\tilde{R}_2}^u], [v_{\tilde{R}_1}^l v_{\tilde{R}_2}^l, v_{\tilde{R}_1}^u v_{\tilde{R}_2}^u]) \end{aligned} \tag{4}$$

$$\begin{aligned} &\tilde{R}_1 \otimes \tilde{R}_2 \\ &= ([\mu_{\tilde{R}_1}^l \mu_{\tilde{R}_2}^l, \mu_{\tilde{R}_1}^u \mu_{\tilde{R}_2}^u], [v_{\tilde{R}_1}^l + v_{\tilde{R}_2}^l - v_{\tilde{R}_1}^l v_{\tilde{R}_2}^l, v_{\tilde{R}_1}^u + v_{\tilde{R}_2}^u - v_{\tilde{R}_1}^u v_{\tilde{R}_2}^u]) \end{aligned} \tag{5}$$

$$\Delta \tilde{R} = ([1 - (1 - \mu_{\tilde{R}}^l)^\Delta, 1 - (1 - \mu_{\tilde{R}}^u)^\Delta], [v_{\tilde{R}}^{l\Delta}, v_{\tilde{R}}^{u\Delta}]) \tag{6}$$

$$\tilde{R}^\Delta = ([\mu_{\tilde{R}}^{l\Delta}, \mu_{\tilde{R}}^{u\Delta}], [1 - (1 - v_{\tilde{R}}^l)^\Delta, 1 - (1 - v_{\tilde{R}}^u)^\Delta]) \tag{7}$$

**Definition 3 [38]** Euclidean distance is computed based on Eq. (8).

$$\begin{aligned} &D_E(\tilde{R}_1, \tilde{R}_2) \\ &= \sqrt{\frac{1}{4} ((\mu_{\tilde{R}_1}^l - \mu_{\tilde{R}_2}^l)^2 + (\mu_{\tilde{R}_1}^u - \mu_{\tilde{R}_2}^u)^2 + (v_{\tilde{R}_1}^l - v_{\tilde{R}_2}^l)^2 + (v_{\tilde{R}_1}^u - v_{\tilde{R}_2}^u)^2)} \end{aligned} \tag{8}$$

**Definition 4 [39]** Normalized decision matrix is computed by Eqs. (9)–(16). Equations (9)–(12) and (13)–(16) are related to the benefit and cost criteria, respectively.

$$\mu_{ij}^l = \frac{\mu_{ij}^l}{\sqrt{\sum_{i=1}^m (2 - v_{ij}^l - v_{ij}^u)^2}} \tag{9}$$

$$\mu_{ij}^u = \frac{\mu_{ij}^u}{\sqrt{\sum_{i=1}^m (2 - v_{ij}^l - v_{ij}^u)^2}} \tag{10}$$

$$v_{ij}^l = 1 - \frac{(1 - v_{ij}^l)}{\sqrt{\sum_{i=1}^m (\mu_{ij}^l + \mu_{ij}^u)^2}} \tag{11}$$

$$v_{ij}^u = 1 - \frac{(1 - v_{ij}^u)}{\sqrt{\sum_{i=1}^m (\mu_{ij}^l + \mu_{ij}^u)^2}} \tag{12}$$

$$\mu_{ij}^l = \frac{(1 - v_{ij}^l)^{-1}}{\sqrt{\sum_{i=1}^m ((\mu_{ij}^l)^{-1} + (\mu_{ij}^u)^{-1})^2}} \tag{13}$$

$$\mu_{ij}^u = \frac{(1 - v_{ij}^u)^{-1}}{\sqrt{\sum_{i=1}^m \left( (\mu_{ij}^l)^{-1} + (\mu_{ij}^u)^{-1} \right)^2}} \quad (14)$$

$$v_{ij}^l = 1 - \frac{(\mu_{ij}^l)^{-1}}{\sqrt{\sum_{i=1}^m \left( (1 - v_{ij}^l)^{-1} + (1 - v_{ij}^u)^{-1} \right)^2}} \quad (15)$$

$$v_{ij}^u = 1 - \frac{(\mu_{ij}^u)^{-1}}{\sqrt{\sum_{i=1}^m \left( (1 - v_{ij}^l)^{-1} + (1 - v_{ij}^u)^{-1} \right)^2}} \quad (16)$$

### 3 Proposed Decision Model

The proposed approach is introduced via a new version of the WDBA method. This approach is presented to obtain the weights of DMs. Moreover, a new combined method is proposed to compute the ranking of alternatives based on a new distance-based approach. This model utilizes the recent papers that have applied the weighting and ranking processes for decision-making and MCDM problems (i.e., [11, 38, 39]).

*Step 1.* Gathering the information from experts  $DM = \{DM_1, DM_2, \dots, DM_s\}$  relevant to the criteria  $C = \{C_1, C_2, \dots, C_n\}$  and the alternatives  $A = \{A_1, A_2, \dots, A_m\}$ .

Furthermore, the decision-making matrix  $(\psi_s)$  based on the  $s$ th expert opinion is shown in Eq. (17).

$$\psi_s = [\psi^s]_{ij} = \begin{bmatrix} \psi_{11}^s & \dots & \psi_{1n}^s \\ \vdots & \ddots & \vdots \\ \psi_{m1}^s & \dots & \psi_{mn}^s \end{bmatrix} \quad (17)$$

where  $i \subseteq \{1, 2, \dots, m\}$  and  $j \subseteq \{1, 2, \dots, n\}$  determine the number of the alternatives and criteria, respectively. Also,  $s \subseteq \{1, 2, \dots, s\}$  presents the number of the DMs.

*Step 2.* Normalizing the decision matrix.

This process is shown in Eqs. (18) and (19) based on Definition 4.

$$\varphi_{ij}^s = \begin{bmatrix} \varphi_{11}^s & \dots & \varphi_{1n}^s \\ \vdots & \ddots & \vdots \\ \varphi_{m1}^s & \dots & \varphi_{mn}^s \end{bmatrix} \quad (18)$$

$$\tilde{\varphi}_{ij}^s = \begin{cases} \left( \begin{bmatrix} \left[ \frac{\mu_{ij}^{sl}}{\sqrt{\sum_{i=1}^m (2 - v_{ij}^{sl} + v_{ij}^{su})^2}}, \frac{\mu_{ij}^{su}}{\sqrt{\sum_{i=1}^m (2 - v_{ij}^{sl} + v_{ij}^{su})^2}} \right] \\ \left[ 1 - \frac{(1 - v_{ij}^{sl})}{\sqrt{\sum_{i=1}^m (\mu_{ij}^{sl} + \mu_{ij}^{su})^2}}, 1 - \frac{(1 - v_{ij}^{su})}{\sqrt{\sum_{i=1}^m (\mu_{ij}^{sl} + \mu_{ij}^{su})^2}} \right] \end{bmatrix} \right) & \text{Benefit criteria} \\ \left( \begin{bmatrix} \frac{(1 - v_{ij}^{sl})^{-1}}{\sqrt{\sum_{i=1}^m ((\mu_{ij}^{sl})^{-1} + (\mu_{ij}^{su})^{-1})^2}}, \frac{(1 - v_{ij}^{su})^{-1}}{\sqrt{\sum_{i=1}^m ((\mu_{ij}^{sl})^{-1} + (\mu_{ij}^{su})^{-1})^2}} \\ \left[ 1 - \frac{(\mu_{ij}^{sl})^{-1}}{\sqrt{\sum_{i=1}^m ((1 - v_{ij}^{sl})^{-1} + (1 - v_{ij}^{su})^{-1})^2}}, \right. \\ \left. 1 - \frac{(\mu_{ij}^{su})^{-1}}{\sqrt{\sum_{i=1}^m ((1 - v_{ij}^{sl})^{-1} + (1 - v_{ij}^{su})^{-1})^2}} \right] \end{bmatrix} \right) & \text{Cost criteria} \end{cases} \quad (19)$$

*Step 3.* Constructing weighted normalized decision matrix with Eq. (20).

$$\chi_{ij}^s = \varphi_{ij}^s \times w_j = \begin{bmatrix} \varphi_{11}^s \times w_j & \dots & \varphi_{1n}^s \times w_j \\ \vdots & \ddots & \vdots \\ \varphi_{m1}^s \times w_j & \dots & \varphi_{mn}^s \times w_j \end{bmatrix} \quad (20)$$

*Step 4.* Computing weights of the DMs.

In this step, the weights expressed by DMs are obtained from average, positive, and negative ideal solutions. Meanwhile, the aggregate values of the experts' opinions are needed to accomplish the DMs' weights.

*Step 4.1.* Obtaining the average, positive, and negative ideal solutions based on weighting normalized decision matrix values by Eqs. (21)-(23).

$$I^* = \left( \left[ \frac{1}{s} \sum_{s=1}^s \mu_{ij}^{*sl}, \frac{1}{s} \sum_{s=1}^s \mu_{ij}^{*su} \right], \left[ \frac{1}{s} \sum_{s=1}^s v_{ij}^{*sl}, \frac{1}{s} \sum_{s=1}^s v_{ij}^{*su} \right] \right) \quad \forall i, j \quad (21)$$

$$I^+ = \left( \left[ \max_s \mu_{ij}^{+sl}, \max_s \mu_{ij}^{+su} \right], \left[ \min_s v_{ij}^{+sl}, \min_s v_{ij}^{+su} \right] \right) \quad \forall i, j \quad (22)$$

$$I^- = \left( \left[ \min_s \mu_{ij}^{-sl}, \min_s \mu_{ij}^{-su} \right], \left[ \max_s v_{ij}^{-sl}, \max_s v_{ij}^{-su} \right] \right) \quad \forall i, j \quad (23)$$

Furthermore, the total of positive ideal solution and the WDBA method depicts the experts' weights. The closer opinions of each DM to the average of the opinions earn a higher weight. For instance, suppose that a university has a teaching competition in which young teachers compete. If there are  $s$  referees as DMs for this tournament, each competitor's final score will be the average of the  $s$  scores provided by DMs. The concepts and computation method have been provided in the recent literature [e.g., 11].

*Step 4.2.* Calculating the distance from average, positive, and negative ideal solutions by Eqs. (24)- (26) based on Definition 3.

$$\phi_A^s = \sqrt{\frac{1}{4} \sum_{i=1}^n \sum_{j=1}^m \left( \left( \mu_{ij}^{sl} - \frac{1}{s} \sum_{s=1}^S \mu_{ij}^{*sl} \right)^2 + \left( \mu_{ij}^{su} - \frac{1}{s} \sum_{s=1}^S \mu_{ij}^{*su} \right)^2 \right) + \left( v_{ij}^{sl} - \frac{1}{s} \sum_{s=1}^S v_{ij}^{*sl} \right)^2 + \left( v_{ij}^{su} - \frac{1}{s} \sum_{s=1}^S v_{ij}^{*su} \right)^2} \tag{24}$$

$$\phi_P^s = \sqrt{\frac{1}{4} \sum_{i=1}^n \sum_{j=1}^m \left( \left( \mu_{ij}^{sl} - \max_s \mu_{ij}^{+sl} \right)^2 + \left( \mu_{ij}^{su} - \max_s \mu_{ij}^{+su} \right)^2 \right) + \left( v_{ij}^{sl} - \min_s v_{ij}^{+sl} \right)^2 + \left( v_{ij}^{su} - \min_s v_{ij}^{+su} \right)^2} \tag{25}$$

$$\phi_N^s = \sqrt{\frac{1}{4} \sum_{i=1}^n \sum_{j=1}^m \left( \left( \mu_{ij}^{sl} - \min_s \mu_{ij}^{+sl} \right)^2 + \left( \mu_{ij}^{su} - \min_s \mu_{ij}^{+su} \right)^2 \right) + \left( v_{ij}^{sl} - \max_s v_{ij}^{+sl} \right)^2 + \left( v_{ij}^{su} - \max_s v_{ij}^{+su} \right)^2} \tag{26}$$

Step 4.3. Obtaining the DMs' values by Eqs. (27) and (28).

$$Dis^s = \max(\phi_P^s, \phi_N^s) \tag{27}$$

$$\Gamma^s = \left( \frac{Dis^s}{\phi_A^s} \right)^{\frac{1}{s}} \tag{28}$$

Step 4.4. Calculating final weights of the DMs by Eq. (29).

$$W^s = \frac{\Gamma^s}{\sum_{s=1}^S \Gamma^s} \quad \forall s \tag{29}$$

Step 5. Aggregating the decision matrix by weights of the DMs by Eq. (30).

$$\begin{aligned} \tilde{\Delta}_{ij} &= \frac{\sum_{s=1}^S W^s \chi_{ij}^s}{\sum_{s=1}^S W^s} = \frac{\sum_{s=1}^S W^s \begin{bmatrix} \varphi_{11}^s \times w_j \cdots \varphi_{1n}^s \times w_j \\ \vdots \quad \ddots \quad \vdots \\ \varphi_{m1}^s \times w_j \cdots \varphi_{mn}^s \times w_j \end{bmatrix}}{\sum_{s=1}^S W^s} \\ &= \frac{\sum_{s=1}^S W^s \begin{bmatrix} ([\mu_{11}^{sl}, \mu_{11}^{su}], [v_{11}^{sl}, v_{11}^{su}]) \times w_j \cdots ([\mu_{1n}^{sl}, \mu_{1n}^{su}], [v_{1n}^{sl}, v_{1n}^{su}]) \times w_j \\ \vdots \quad \ddots \quad \vdots \\ ([\mu_{m1}^{sl}, \mu_{m1}^{su}], [v_{m1}^{sl}, v_{m1}^{su}]) \times w_j \cdots ([\mu_{mn}^{sl}, \mu_{mn}^{su}], [v_{mn}^{sl}, v_{mn}^{su}]) \times w_j \end{bmatrix}}{\sum_{s=1}^S W^s} \end{aligned} \tag{30}$$

Step 6. Determining the positive and negative ideal solutions by Eqs. (31) and (32).

$$PIS^+ = \left( \left[ \max_i \mu_{ij}^{+l}, \max_i \mu_{ij}^{+u} \right], \left[ \min_i v_{ij}^{+l}, \min_i v_{ij}^{+u} \right] \right) \quad \forall j \tag{31}$$

$$NIS^- = \left( \left[ \min_i \mu_{ij}^{-l}, \min_i \mu_{ij}^{-u} \right], \left[ \max_i v_{ij}^{-l}, \max_i v_{ij}^{-u} \right] \right) \quad \forall j \tag{32}$$

Step 7. Computing the distances from positive and negative ideal solutions by Eqs. (33) and (34).

$$D_i^+ = \sqrt{\frac{1}{4} \sum_{j=1}^m \left( \left( \mu_{ij}^l - \max_i \mu_{ij}^{+l} \right)^2 + \left( \mu_{ij}^u - \max_i \mu_{ij}^{+u} \right)^2 \right) + \left( v_{ij}^l - \min_i v_{ij}^{+l} \right)^2 + \left( v_{ij}^u - \min_i v_{ij}^{+u} \right)^2} \tag{33}$$

$$D_i^- = \sqrt{\frac{1}{4} \sum_{j=1}^m \left( \left( \mu_{ij}^l - \min_i \mu_{ij}^{+l} \right)^2 + \left( \mu_{ij}^u - \min_i \mu_{ij}^{+u} \right)^2 \right) + \left( v_{ij}^l - \max_i v_{ij}^{+l} \right)^2 + \left( v_{ij}^u - \max_i v_{ij}^{+u} \right)^2} \tag{34}$$

Step 8. Obtaining initial ranking values of the collective index by Eq. (35).

$$\varrho_i = \left( \frac{D_i^-}{D_i^+} \right)^{\frac{1}{j}} + \left( \frac{D_i^-}{D_i^+} \right) \tag{35}$$

Step 9. Computing the secondary ranking values of the collective index by Eq. (36) based on the cost and benefit weights of the criterion ( $w_j^-, w_j^+, w_j^+ + w_j^- = 1$ ).

$$\theta_i = \sum_{j=1}^n w_j^+ \left( \frac{D_i^-}{\sum_{i=1}^m D_i^-} \right) - \sum_{j=1}^n w_j^- \left( \frac{D_i^+}{\sum_{i=1}^m D_i^+} \right) \tag{36}$$

Step 10. Calculating the final rank by Eq. (37). The collective index is provided to integrate two different ranking values that are obtained from two different ranking approaches.

$$C_i = \frac{\theta_i + \varrho_i}{2} \tag{37}$$

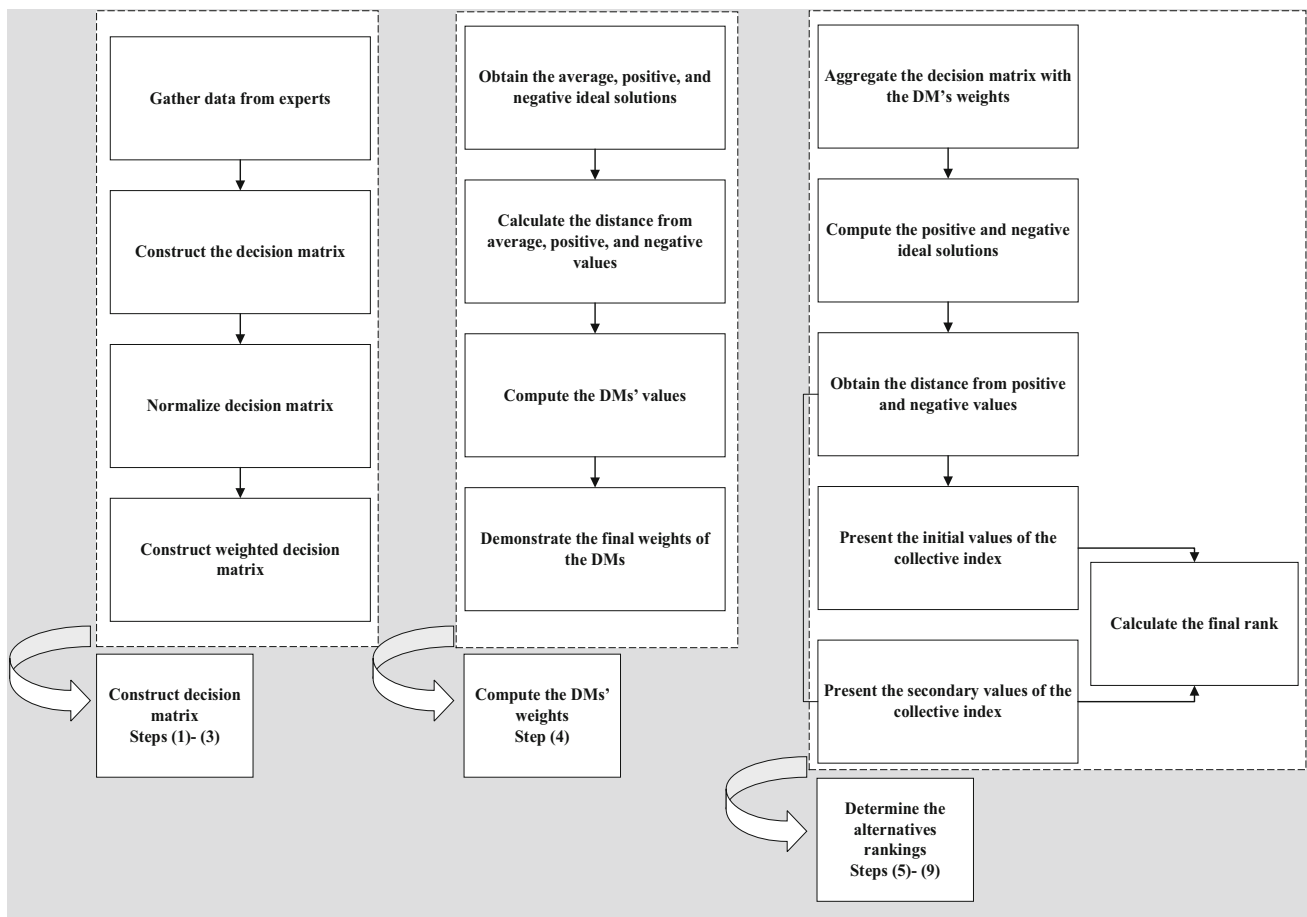


Fig. 1 Structure of the proposed approach

Eventually, the alternatives can be ranked in descending order. The structure of the decision approach is depicted in Fig. 1.

### 4 Experimental Example

Here, an empirical example from the literature [28] is solved to determine the performance of the proposed approach. The decision matrix is developed via the opinions of three DMs. 24 criteria and their weights are listed in Table 1.

Four kinds of alternatives are applied in handling the COVID-19 pandemic condition with DTs, including strengths, weaknesses, opportunities, and threats (SWOT). The two first sections are internal elements, and the two other parts are external factors. Afterward, the linguistic variables for experts' judgments are determined in Table 2 [40]. Furthermore, Table 3 constructs the decision matrix based on the three experts' opinions.

Hence, the values of  $\phi_A^s$ ,  $\phi_P^s$ , and  $\phi_N^s$  which are obtained by Eqs. (24)–(26), are determined in Table 4. Moreover, Table

4 shows the values of the DMs ( $\Gamma^s$ ) and their final weights ( $W^s$ ) using Eqs. (27) and (28), respectively.

According to Table 4, the first DM has a higher priority than other experts, and DMs' opinions may have a great influence on final decisions. In addition, Table 5 shows the positive and negative ideal solutions distances ( $D_i^+$  and  $D_i^-$ ), the initial ranking value of the collective index ( $q_i$ ), the secondary ranking value of the collective index ( $\theta_i$ ), the final value of the collective index ( $C_i$ ), and the final ranking of alternatives that are obtained by Eqs. (33)–(37), respectively.

The obtained result indicates the superiority of the first alternative (i.e., strengths) over other options in the COVID-19 pandemic conditions for selecting an appropriate DT strategy. In other words, in the critical status of the COVID-19 pandemic, focusing on strengths is more important than other alternatives in the DT selection, which can help make the proper decision more effectively. Afterward, weaknesses, opportunities, and threats have the next priorities compared to each other.



**Table 1** Criteria description and weight evaluation [41]

Criteria	Symbol	Criteria weights
Digital treatment	$C_1$	0.041
Awareness and training	$C_2$	0.037
Health hazard prediction	$C_3$	0.022
Non- virtual support	$C_4$	0.027
Medicine development	$C_5$	0.037
Economic interventions	$C_6$	0.075
Digital divide	$C_7$	0.022
Lack of Digital knowledge	$C_8$	0.043
Cost inefficiency	$C_9$	0.045
Mock information	$C_{10}$	0.054
Lack of reliable data	$C_{11}$	0.034
Insecure applications	$C_{12}$	0.048
Accurate prediction system	$C_{13}$	0.035
Automatization of Healthcare	$C_{14}$	0.032
Research framework in Epidemiology	$C_{15}$	0.029
Digital health education	$C_{16}$	0.052
Digital diagnosis	$C_{17}$	0.029
Health information systems (HIS)	$C_{18}$	0.025
Non-digital interferences	$C_{19}$	0.048
Digital stratification	$C_{20}$	0.033
Privacy worries	$C_{21}$	0.057
Unaffordability	$C_{22}$	0.036
Exacerbation of paranoia	$C_{23}$	0.065
Infodemic risk	$C_{24}$	0.074

**Table 2** Linguistic terms to evaluate criteria and alternatives [40]

Linguistic variables	IVIF values
Extremely low (EL)	([0.00,0.05], [0.90,0.90])
Very low (VL)	([0.05,0.10], [0.80,0.90])
Low (L)	([0.10,0.20], [0.70,0.80])
Medium low (ML)	([0.30,0.40], [0.50, 0.60])
Medium (M)	([0.50,0.50], [0.50, 0.50])
Medium high (MH)	([0.50,0.60], [0.30, 0.40])
High (H)	([0.70,0.80], [0.10,0.20])
Very high (VH)	([0.80, 0.90], [0.50, 0.10])
Extremely high (EH)	([0.90,0.90], [0.00,0.05])

## 5 Result and Discussion

In this section, the effectiveness and advantages of the proposed model are presented by comparing it with IVIF-TOPSIS and IVIF-VIKOR methods. The final ranks of the alternatives are alike, and the introduced model is valid. Table 6 determines the collective index of the proposed ranking model, IVIF-TOPSIS, and IVIF-VIKOR approaches. This

table illustrates that the final ranking values result in similar outcomes.

Furthermore, for the proposed model, three various scenarios are carried out for each criterion. In this analysis, the weight of each index is switched to 0.1, 0.5, and 0.9, respectively, although others are proportionally kept fixed. The collective index of alternatives is reobtained with these new criteria weights. It should be noted that the sum of weights

**Table 3** Linguistic values of criteria performance

Criteria	DMs	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	A <sub>4</sub>
C <sub>1</sub>	DM <sub>1</sub>	MH	M	ML	MH
	DM <sub>2</sub>	M	ML	H	ML
	DM <sub>3</sub>	H	MH	M	H
C <sub>2</sub>	DM <sub>1</sub>	H	MH	M	H
	DM <sub>2</sub>	H	L	ML	H
	DM <sub>3</sub>	M	H	M	H
C <sub>3</sub>	DM <sub>1</sub>	MH	ML	ML	MH
	DM <sub>2</sub>	VH	MH	H	M
	DM <sub>3</sub>	H	L	ML	H
C <sub>4</sub>	DM <sub>1</sub>	L	M	M	H
	DM <sub>2</sub>	MH	VH	ML	M
	DM <sub>3</sub>	M	H	M	H
C <sub>5</sub>	DM <sub>1</sub>	M	ML	L	M
	DM <sub>2</sub>	M	L	H	ML
	DM <sub>3</sub>	MH	ML	L	L
C <sub>6</sub>	DM <sub>1</sub>	M	M	M	MH
	DM <sub>2</sub>	VH	M	ML	M
	DM <sub>3</sub>	M	VL	M	VL
C <sub>7</sub>	DM <sub>1</sub>	MH	ML	L	L
	DM <sub>2</sub>	M	VL	M	VL
	DM <sub>3</sub>	H	M	VH	H
C <sub>8</sub>	DM <sub>1</sub>	MH	H	M	MH
	DM <sub>2</sub>	H	MH	ML	L
	DM <sub>3</sub>	M	M	VH	H
C <sub>9</sub>	DM <sub>1</sub>	ML	H	MH	M
	DM <sub>2</sub>	MH	M	VH	VL
	DM <sub>3</sub>	H	VH	H	M
C <sub>10</sub>	DM <sub>1</sub>	VH	EH	MH	H
	DM <sub>2</sub>	M	H	H	MH
	DM <sub>3</sub>	H	MH	H	M
C <sub>11</sub>	DM <sub>1</sub>	MH	EH	VH	M
	DM <sub>2</sub>	VH	MH	MH	ML
	DM <sub>3</sub>	H	ML	L	M
C <sub>12</sub>	DM <sub>1</sub>	H	VH	H	M
	DM <sub>2</sub>	H	MH	H	M
	DM <sub>3</sub>	H	ML	L	M
C <sub>13</sub>	DM <sub>1</sub>	MH	MH	H	ML
	DM <sub>2</sub>	ML	M	M	MH
	DM <sub>3</sub>	M	H	ML	H

equals 1 in each scenario. The effects of the changes on alternative ranks are determined in Fig. 2.

In Fig. 2, A<sub>1</sub> can be determined as the best alternative with three varying weights of the criteria for COVID-19 DT selection; it is superior to the four options in all sensitivity

analyses. This denotes that the decisions made by the proposed approach are robust and effective.

Afterward, the criteria weights change among random numbers to compute the independency of DMs' weights with



**Table 3** (continued)

Criteria	DMs	A <sub>1</sub>	A <sub>2</sub>	A <sub>3</sub>	A <sub>4</sub>
C <sub>14</sub>	DM <sub>1</sub>	MH	H	M	VH
	DM <sub>2</sub>	H	MH	MH	MH
	DM <sub>3</sub>	VH	H	ML	M
C <sub>15</sub>	DM <sub>1</sub>	L	H	M	H
	DM <sub>2</sub>	VH	VH	VH	M
	DM <sub>3</sub>	M	ML	H	MH
C <sub>16</sub>	DM <sub>1</sub>	M	H	ML	H
	DM <sub>2</sub>	VH	H	ML	M
	DM <sub>3</sub>	M	ML	H	ML
C <sub>17</sub>	DM <sub>1</sub>	M	H	ML	ML
	DM <sub>2</sub>	M	ML	H	H
	DM <sub>3</sub>	H	ML	M	H
C <sub>18</sub>	DM <sub>1</sub>	L	MH	MH	H
	DM <sub>2</sub>	ML	MH	ML	L
	DM <sub>3</sub>	H	ML	L	VL
C <sub>19</sub>	DM <sub>1</sub>	MH	M	M	H
	DM <sub>2</sub>	VH	MH	M	M
	DM <sub>3</sub>	M	VH	H	M
C <sub>20</sub>	DM <sub>1</sub>	L	ML	ML	H
	DM <sub>2</sub>	ML	H	MH	ML
	DM <sub>3</sub>	ML	ML	ML	M
C <sub>21</sub>	DM <sub>1</sub>	MH	H	ML	ML
	DM <sub>2</sub>	H	H	L	M
	DM <sub>3</sub>	M	L	H	MH
C <sub>22</sub>	DM <sub>1</sub>	M	H	ML	ML
	DM <sub>2</sub>	MH	ML	H	H
	DM <sub>3</sub>	H	ML	ML	MH
C <sub>23</sub>	DM <sub>1</sub>	ML	H	MH	H
	DM <sub>2</sub>	ML	MH	ML	ML
	DM <sub>3</sub>	MH	ML	L	VL
C <sub>24</sub>	DM <sub>1</sub>	MH	M	MH	H
	DM <sub>2</sub>	H	H	M	MH
	DM <sub>3</sub>	MH	VH	H	M

**Table 4** Final weights of the DMs

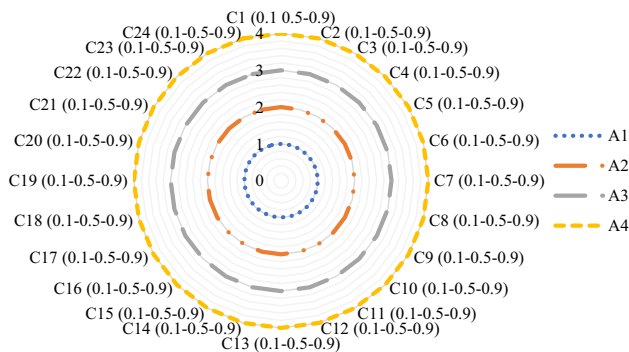
DMs	$\phi_A^s$	$\phi_P^s$	$\phi_N^s$	$\Gamma^s$	$W^s$
DM <sub>1</sub>	0.00612	0.00825	0.08518	2.40496	0.41747
DM <sub>2</sub>	0.00656	0.00842	0.07004	2.20183	0.38221
DM <sub>3</sub>	0.00858	0.01318	0.00844	1.15395	0.20031

**Table 5** Final alternatives ranking

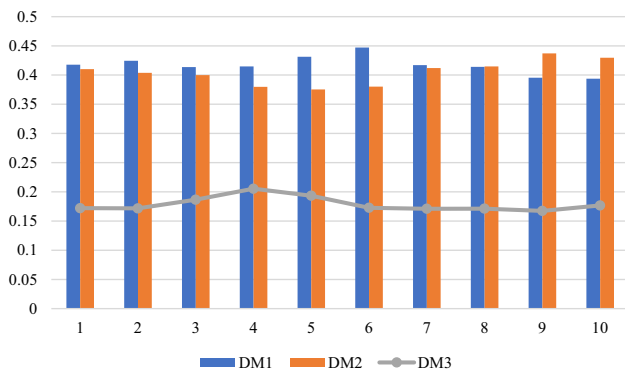
Alternatives	$D_i^+$	$D_i^-$	$\rho_i$	$\theta_i$	$C_i$	Final rank
A <sub>1</sub>	0.00290	0.00678	3.36950	0.02061	1.69505	1
A <sub>2</sub>	0.00441	0.00566	2.29196	0.01720	1.15458	2
A <sub>3</sub>	0.00582	0.00416	1.70054	0.01264	0.85659	3
A <sub>4</sub>	0.00567	0.00380	1.65389	0.01155	0.83272	4

**Table 6** Comparisons among three ranking approaches

Alternatives	IVIF-TOPSIS	Ranking	IVIF-VIKOR	Ranking	Proposed approach	Ranking
A <sub>1</sub>	0.70002	1	0.62587	1	1.69505	1
A <sub>2</sub>	0.56171	2	0.60354	2	1.15458	2
A <sub>3</sub>	0.41672	3	0.57412	3	0.85659	3
A <sub>4</sub>	0.40135	4	0.563214	4	0.83272	4



**Fig. 2** Results of sensitivity analysis for the proposed model based on the criteria weights



**Fig. 3** Sensitivity analysis outcomes on dependencies among DMs weights and criteria weights

these values. In 10 different cases considering various criteria weights, the first DM often has a higher degree than the second DM; Fig. 3 demonstrates this point clearly.

## 6 Conclusion

COVID-19 is a pandemic that has not yet been passed, appearing in China and developing in the world. Increasing the pandemic causes healthcare system organizations to face many difficulties. Hence, governments make efforts to control the behavior of the pandemic in their lifestyle. These criteria are insufficient, and so it is essential to make sure that the pandemic is managed correctly with the most suitable strategy. Most developed countries have used the digital technology (DT) to support health systems. Meanwhile, the DT selection and implementation by healthcare organizations need to be assessed and contrasted. In this regard, a multi-criteria decision-making problem (MCDM) problem arises, where many alternatives should be assessed under more than one ranking index. Nevertheless, due to uncertainties in the addressed problem and the lack of information and contradictions among a group of experts, interval-valued intuitionistic fuzzy sets (IVIFSs) that allow decision-makers (DMs) to evaluate in a broader area should be addressed. IVIFS is a powerful tool to control the vagueness condition. Using IVIFSs, especially in MCDM methods, ambiguity and uncertainty are described more strongly, and consequently, the decision-making procedure can be handled more precisely. In this respect, one of the essential issues utilized in this paper is introducing a new MCDM model considering the IVIFSs. This issue is caused by viewing the real-world uncertainty conditions and real application requirements. IVIFS is a powerful tool that presents the uncertain amounts among the interval values. Therefore, two new methods based on IVIFSs have been proposed in this paper to calculate the weights of DMs and the ranking of the alternatives. An extended weighting method is applied to determine the weights of the experts using the WDBA method. Afterward, a new ranking method is proposed by computing the positive and negative

ideal distances via two various ranking approaches. Finally, a new collective index method is presented to aggregate the rankings' values. Additionally, the mentioned methods are used to select the best DT strategy for governments. Alternatives, criteria, and information have been applied in the literature. According to the results, the first DM has high priority than other experts, and the first alternative is superior to use with the governments. This alternative is related to focusing on the strengths of the DT that helps the manager control the pandemic situation at an appropriate time. Afterward, the sensitivity analysis has been conducted to compute the independency of the proposed approach from the criteria' weights. Firstly, the criteria weight independency is considered using the sensitivity analysis performed on the new extended DM weighting method. Secondly, the independence of the new hybrid ranking method is measured on the criteria' weights. In these two analyses, the DMs' weights and rankings of the alternatives are independent of criteria' weights, and the results of the proposed new hybrid approach are robust and reliable. Likewise, the comparisons among the proposed model and two well-known IVIF-decision approaches, i.e., IVIF-technique for order of preference by similarity to ideal solution (IVIF-TOPSIS) and IVIF-ViseKriterijumska Optimizacija I Kompromisno Resenje, in Serbian (IVIF-VIKOR), have shown that the proposed approach has high performance to compute the ranking of alternatives. The final ranking values are valid by considering these two IVIF-multi-criteria decision approaches.

For future suggestions, the proposed model can be developed for other new types of fuzzy sets (FSs), e.g., interval-valued hesitant fuzzy sets and interval type-2 fuzzy sets. Various kinds of the MCDM method can be extended, in the related literature on complex decision making [42–47], to compare with this proposed approach. Moreover, the optimization technique can be used to compute the weights of the DMs in reality.

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## Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

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