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An IT2FS-PT^3 based emergency response plan evaluation with MULTIMOORA method in group decision making

Jindong Qin [a,b,*], Xiaoyu Ma [a]

[a] School of Management, Wuhan University of Technology, Wuhan Hubei, 430070, China

[b] Research Center for Data Science and Intelligent Decision Making, Wuhan University of Technology, Wuhan Hubei, 430070, China

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ABSTRACT

The eruption of COVID-19 at the beginning of 2020 has sounded the alarm, making experts pay more attention to public health emergency events. A suitable emergency response plan plays a vital role in handling emergency events. Therefore, this paper focuses on the evaluation of emergency response plans among a set of group in the comprehensive prospect, and an emergency decision making method integrated with the interval type-2 fuzzy information based on the third generation prospect theory (PT^3) and the extended MULTIMOORA method is proposed. Individuals express their preferences using some given linguistic terms set. Furthermore, considering the conflicts may occur in the group, a convergent iterative algorithm is designed for group consensus reaching. Then, the stochastic multi-criteria acceptability analysis (SMAA) method and the Borda Count (BC) method are generated to combine the results instead of the dominance theory in MULTIMOORA system. Finally, based on the background of the COVID-19 pandemic from Wuhan, a case study about the selection of emergency response plan and the corresponding sensitivity and comparative analysis are exhibited to explain the effectiveness of the proposed method.

1. Introduction

Emergency events refer to any situation arising from sudden and unforeseen catastrophe that may cause casualties, economic losses, environmental damage, and serious social harm [1]. In China, kinds of emergency events have had severely negative impact on people's life and social development, especially for the public health emergency events, e.g. the outbreak of SARS in 2003, the Wenchuan Earthquake in Sichuan, China on May 12, 2008. Recently, the new corona virus (COVID-19) in the end of 2019 caused huge loss of lives and properties. More seriously, the confirmed and suspected cases of COVID-19 have been increasing without ending not only in Wuhan, Hubei Province, but also China and the world. As early as January 30, 2020, the World Health Organization (WHO) announced COVID-19 as the eruption a public health emergency of international concern. In the meanwhile, China declared a travel quarantine of Wuhan and other 16 cities, encompassing a population of 45 million [2]. By October 18, 2021, a total of 4,512 fatalities and 68,303 laboratory-confirmed cases had been reported in Hubei Province. With the continuous exponential increase of the number of pandemic cases, the Chinese government has taken powerful preventive measures followed by the highest level of class A infectious diseases based on the Law of the People's Republic of China on Prevention and Treatment of Infectious Diseases (LPTID) [3]. China has imposed strict restrictions on public activities containing a large number of people, thus reducing the possibility of virus transmission, which exists a negative impact on economy development and caused the unemployment on a certain scale.

Therefore, researchers proposed the corresponding emergency response plans to minimize destructive consequences for people's healthy life and the normal development of society. Apparently, decision makers (DMs) from emergency department are supposed to select the suitable and desirable emergency response plan when tacking with these devastating hazards. Generally speaking, the assessments of emergency response plans are complicated, owing to the uncertain and partial information of the catastrophic scenarios and the multi-perspectives of DMs. Hence, many researchers have focused on this topic and made great contributions [1,4–9]. For instance, Hämäläinen et al. [1] used a multi-attribute utility theory analysis in a simulated nuclear emergency, Levy and Taji [4] discussed the hazard planning and emergency management in the group analytic network process (GANP). Ferreira et al. [5] presented a new urban fire emergency plan assessment method using the integrated geographical information system (GIS) tool. Shamim et al. [6] integrated the

* Corresponding author at: School of Management, Wuhan University of Technology, Wuhan Hubei, 430070, China.

E-mail addresses: qinjindongseu@126.com (J. Qin), 15071397352@163.com (X. Ma).

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Delphi technique with a mathematical model to qualify the performance of emergency planning response (EPR) in a real case of a major accident in the process industry. Liu et al. [9] dealt with the decision making in emergency response plans about the simulation of H1N1 infectious diseases based on Fault Tree Analysis. These studies mentioned above provided various decision making methods for the selection of the optimal emergency response plan. Whereas, in the existing literatures about emergency response plans evaluation, the characteristics of the DMs are seldomly considered. It is worth noting that the decision making process in emergency events tend to be vague and uncertain due to the inadequate information. A substantial body of psychological studies on human behaviors show that DMs incline to express the reference dependence, preference reversal and other typical characteristics in the circumstance of fuzzy and uncertain events [10–13]. Hence, the psychological behaviors of DMs should be taken into consideration.

Since, Kahneman and Tversky [10] introduced the alternative model, named prospect theory (PT) to replace the expected utility theory considering human behaviors, the behavioral decision making theories showed rapid development, such as the regret theory [14]. Afterwards, they extended the original PT called cumulative prospect theory (CPT) with using the cumulative decision weights [12], inspired by the rank and sign dependent utility(RSDU) by Luce and Fishburn [15]. Then, Schmidt et al. [13] founded that both PT and CPT have a common limitation: the reference points in the prospects are supposed to be certainties, which cannot be applied to solve this type of situations: DMs purchased lotteries and had the chance to sell or exchange them. Hence, they expanded these theories and proposed the third generation prospect theory (PT^3), which retained the power of previous version of PT and increased new proposals: the value-maximal buying prices (WTP) and minimal selling prices (WTA). It is easy to see that PT^3 has the wider range to solve various decision making problems in risk and uncertain environment [16–18]. For instance, Wang et al. [17] constructed the three-way decision model based on PT^3 and Z-numbers to solve the task assessment in human–machine collaboration. Feng et al. [18] applied PT^3 to illustrate the reduced demand of U.S. corn and soybean producers. Thus, the idea to incorporate PT^3 into the assessments of emergency response plans deserves more attention. Simultaneously, one should consider the features of public health emergency events affected by time series. The consequences caused by COVID-19 are changed over time. Wuhan switched from a high-risk area in March into a low-risk area in June. Hence, the time factor is supposed to be considered for the formation and updating of dynamic reference points. We introduce the prediction method of reference points in the time line referred in [19], which proposed a parsimonious formula to predict reference points.

Furthermore, in a real emergency scenario, DMs often face the incomplete and fuzzy information, which means DMs prefer to make judgments on linguistic terms than single numbers in the complex situations. Then type-2 fuzzy sets (T2FSs) is regarded as the ideal tool to qualify terms, which offers capabilities to handle higher level uncertain problems. In light of the computational complexity mathematical calculation, researchers intend to choose interval type-2 fuzzy sets (IT2FSs), known as the special type of T2FSs [20–26], which are characterized by the membership values of numerical intervals, the benefits of IT2FSs can be summarized as: IT2FSs are the extension of type-1 fuzzy sets (T1FSs), they can handle higher degrees of uncertainty and ambiguity when the preference information expressed linguistically. Moreover, IT2FSs are relatively simpler among the higher order fuzzy sets [22]. As a result, in this proposed model, the linguistic terms set in the form of IT2FSs is served as the evaluation systems for DMs. Meanwhile, the evaluation of emergency response plans by a set of DMs can be viewed as multiple criteria group decision making (MCGDM) process. Some integrated hazard assessments using GANP [4], fuzzy analytic hierarchy process (FAHP) [27], multiple multi-objective optimization by ratio analysis (MULTIMOORA) [28] and other multi-criteria decision making (MCDM) methods see in [27,29]. Among these approaches, MULTIMOORA, initially introduced by Brauers and Zavadska [30], is an effective decision making method for the benefits of computational time, the simplicity and stability for mathematical calculations [31]. There are wide applications of MULTIMOORA method, for instance, the green supply chain management [32], healthcare management [33] and other field referred in [34]. Since [30] first proposed the Multi-Objective Optimization by Ratio Analysis (MOORA) method, which contained two major parts: Ratio System (RS) and Reference Point Theory (RPT). Afterwards, the Full Multiplicative Form (FMF) method is considered, then the MULTIMOORA (MOORA plus FMF) method is constructed in [35], which derives the three subordinate rankings. At present, there are abundant ranking aggregation techniques to fuse these results [24,32,36], the dominance theory is the classical integration tool in the initial MULTIMOORA method [35]. Furthermore, other aggregation tools are proposed to take place the theory which emerge the better robustness. For instance, Celik et al. [24] applied the dominance directed graph, rank position method and the Borda Count (BC) method [37] to integrate the three results. Besides using the improved BC method as the fusion tool, Mi et al. [32] applied the stochastic multi-criteria acceptability analysis (SMAA) to increase the stochastic uncertain factors for the input of MULTIMOORA. The more fusion tools on MULTIMOORA method refer to Ref. [36]. Inspired by these above studies, we choose the improved BC method to aggregate the three subordinate methods, instead of adding the rankings of these three methods directly, we consider the integration of the utility values, which are based on the cardinal numbers and further conform the Arrow's opinion [38], that is, a cardinal utility implies an ordinal preference but not vice versa. Besides, considering the advantages of SMAA in dealing with uncertain problems, we introduce the combination of SMAA and MULTIMOORA by disturbing the weights of criteria. SMAA is an efficient method to deal with decision problems where little or no weight information is available, which is suitable to assist DMs for tackling the corresponding criteria weights of emergency response plans. The detailed content on SMAA refers to Refs. [39–41]. Hence, in this study, owing to the randomness and contingency of emergency events, we integrate SMAA method with MULTIMOORA method to form the extended MULTIMOORA method to deal with the issue of information uncertainty in the assessment of emergency response plans.

Furthermore, in the evaluation process of emergency response plans, all DMs should reach consensus to avoid conflicts and obtain higher-quality decision result with timely feedback [4,42]. Generally, there are two steps to reach group consensus: (i) aggregate individual decision information into a group decision result, and (ii) verify whether the result have reach consensus, if not, use the relative algorithm to modify the group decision result. Moreover, different distance functions are usually applied to reflect consensus measures in [43,44]. In this paper, a standard Euclidean-based distance measurement is proposed to calculate the degree of group consensus. Simultaneously, the distance threshold is given as referred to Refs. [43,45] and the corresponding convergent iterative algorithm is put forward to modify the group decision result. Hence, on the basis of considering group consensus, we combine the IT2FSs, PT^3, and the extended MULTIMOORA method to construct the evaluation system of emergency response plans in the group set. Then a novel

IT2FS-PT^3 with the extended MULTIMOORA method in a group emergency response plan evaluation is proposed.

To emphasize the reasons for the novel combination of IT2FS, PT^3 and MULTIMOORA method, it can be illustrated as follows: considering that it is difficult to acquire enough essential information in real emergency events and the evolution of diseases is hard to estimate. Thus, it is unreasonable for DMs to assign the accurate numerical assessments to the emergency response plans. Hence, we apply the linguistic terms to assist DMs to make evaluations with IT2FSs served as the quantitative tool. In the meanwhile when dealing with catastrophes, PT^3 has a good performance in dealing with the subjectivity of decision making process. Furthermore, the dynamic reference points suit well to the timeliness of emergency events. In the end, it is vital to choose an effective MCDM method and the reasonable establishment of the relative criteria weight due to the huge pessimistic impact brought by emergency events, the MULTIMOORA method is more robust and objective from integrating three utility functions than other MCDM methods, such as AHP in [46], TOPSIS in [46], VIKOR in [47], etc. In addition, SMAA method can be used with uncertain criteria preference information [41].

Based on the above discussion, the major contributions of the proposed model can be summarized as follows.

- We take into consideration the personality characteristics of DMs, then introduce the PT^3 combined the extended MULTIMOORA method to make assessments to the emergency response plans. In detail, we associate the time line with the setting of dynamic reference points, which is in line with time factor of emergency events and the SMAA method is applied to randomize the criteria weight to increase the stability and robustness of the final ranking results.
- We apply the linguistic evaluation matrix to make DMs more flexible in expressing their preferences, and for the qualification of the IT2FSs-based linguistic terms in PT^3, there are six possible cases to construct the corresponding prospect matrix. Meanwhile, we design a standard Euclidean-based distance formula to measure the level of agreement between the individuals and the group, the relative convergent consensus iterative algorithm is given as well.
- We present an emergency response plan assessments case based on COVID-19 erupted in Wuhan, China. The corresponding risk states can be referred from Wuhan Municipal Health Commission (wjw.wuhan.gov.cn), which further illustrates the effectiveness and practicality of this method.

The remainder of this paper is arranged as follows. Section 2 briefly exhibits the knowledge about IT2FSs, PT^3 and the extended MULTIMOORA method. Section 3 describes the main model of this paper and the solution procedures of the optimal emergency response plan selection. Section 4 gives a case study on COVID-19 infectious diseases to demonstrate the feasibility of this proposed model. In the meanwhile, sensitivity analysis and comparative analysis are taken into consideration as well. Section 5 presents a further discussion. Finally, Section 6 summarizes conclusions, limitations, and future studies.

2. Preliminaries

In this section, the basic concepts about IT2FSs, PT^3 and the extended MULTIMOORA method are briefly discussed.

2.1. Interval type-2 fuzzy sets

IT2FSs, served as a kind of special T2FSs have a wider application for its computational simplicity [48]. The important associated concepts are given as below.

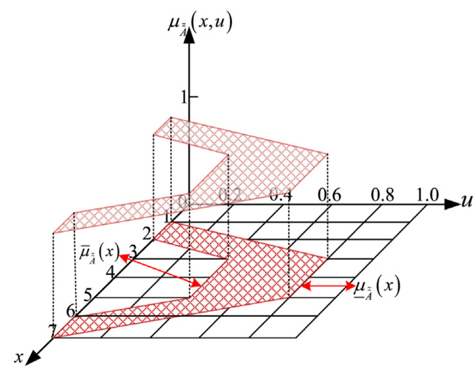

Fig. 1. An example of the IT2FS MF in a 3-D plane.

Definition 1 ([49]).. Let $\tilde{\tilde{A}}$ be a general T2FS, characterized by type-2 membership function (MF) $\mu_{\tilde{\tilde{A}}}$ in the universe of discourse X it can be expressed as follows.

$$\tilde{\tilde{A}} = \int_{x\in X}\int_{u\in J_x} \mu_{\tilde{\tilde{A}}}(x,u)/(x,u) \tag{1}$$

where J_x is the primary MF, satisfied $0 \leqslant J_x \leqslant 1$, $\mu_{\tilde{\tilde{A}}}(x,u) = 1$ stands for the secondary MF with $0 \leqslant \mu_{\tilde{\tilde{A}}}(x,u) \leqslant 1$ and $\iint\cdot$ represents the union contained all admissible x and u.

Definition 2 ([49]).. If all $\mu_{\tilde{\tilde{A}}}(x,u) = 1$ then, an IT2FS can be expressed as follows.

$$\tilde{\tilde{A}} = \int_{x\in X}\int_{u\in J_x} 1/(x,u) \quad J_x \in [0,1] \tag{2}$$

where Fig. 1 displays an example of IT2FS MF in a 3-D plane, which the construction of IT2FS is intuitively presented, and the lower MF (LMF) and upper MF (LMF) of the IT2FS are type-1 MF, respectively.

Definition 3 ([50]).. Let c_l and c_r be the left and right end-points of the centroid of an IT2FS satisfying the following equations.

$$c_l = \min_{\forall\theta(x_i)\in[\bar{\mu}_{\tilde{\tilde{A}}}(x_i),\underline{\mu}_{\tilde{\tilde{A}}}(x_i)]} \frac{\sum_{i=1}^{N} x_i\theta_i}{\sum_{i=1}^{N}\theta_i} \tag{3}$$

and

$$c_r = \max_{\forall\theta(x_i)\in[\bar{\mu}_{\tilde{\tilde{A}}}(x_i),\underline{\mu}_{\tilde{\tilde{A}}}(x_i)]} \frac{\sum_{i=1}^{N} x_i\theta_i}{\sum_{i=1}^{N}\theta_i} \tag{4}$$

where $x \in X$, $\theta(x_i)$ $(i = 1,\ldots,N)$ is the value of MF $\tilde{\tilde{A}}$ IT2FS, $\bar{\mu}_{\tilde{\tilde{A}}}(x_i)$ is the value of LMF of the IT2FS and $\underline{\mu}_{\tilde{\tilde{A}}}(x_i)$ denotes the UMF, which can be seen in Fig. 1. We can find the optimal values of c_l and c_r by KM algorithm, for the detail procedures about KM algorithm see in [51].

Remark 1. In order to better understand the operation mechanism of IT2FSs, there exhibits a numerical example for illustration with its MFs in Fig. 1: The IT2FS $\tilde{\tilde{A}} = (\tilde{\tilde{A}}^L, \tilde{\tilde{A}}^U) = ((a_1^L, a_2^L, a_3^L, a_4^L, H(\tilde{\tilde{A}}^L), (a_1^U, a_2^U, a_3^U, a_4^U, H(\tilde{\tilde{A}}^U))))$, where $\tilde{\tilde{A}}^L$ and $\tilde{\tilde{A}}^U$ are the TIFSs, and $a_1^L, a_2^L, a_3^L, a_4^L, a_1^U, a_2^U, a_3^U, a_4^U$ are the reference points of $\tilde{\tilde{A}}$ on x axis, and $H(\tilde{\tilde{A}}^L), H(\tilde{\tilde{A}}^U) \in [0,1]$ represent the membership values in the LMF $\bar{\mu}_{\tilde{\tilde{A}}}(x)$ and UMF $\underline{\mu}_{\tilde{\tilde{A}}}(x)$ respectively. In Fig. 1, $a_1^U = 1$, $a_1^L = 2$, $a_2^L, a_2^U = 3$, $a_3^L, a_3^U = 5$, $a_4^L = 6$, $a_4^U = 7$, $H(\tilde{\tilde{A}}^L) = 0.4$ and $H(\tilde{\tilde{A}}^U) = 0.8$.

2.2. Third generation prospect theory

There are some prerequisites about PT^3 are given as follows.

Definition 4 ([13]).. Let $S = \{s_i | i = 1, 2, \ldots, n\}$ be a finite state space, containing the states $PI = \{\pi_i \geq 0, \sum_i \pi_i = 1 | i = 1, 2, \ldots, n\}$ be the objective probability set associated with S, $X = \{x_i | i = 1, 2, \ldots, n\}$ is the result of state under probability PI, F be the set of all acts, and acts $f, h \in F$ are the functions from S to X, satisfied $f(s_i) \in X$, $h(s_i) \in X$, where h is the reference act of f, the value function used in the PT^3 can be expressed in the following form.

$$v(f,h) = \begin{cases} (f(s_i) - h(s_i))^\alpha & f \geq h \\ -\sigma (h(s_i) - f(s_i))^\alpha & f < h \end{cases} \tag{5}$$

where the parameters α and σ are strictly positive, and α associated with the curvature of the value functions of gain and losses, σ is the risk-aversion parameter, which controls the DMs' attitudes to gain and loss.

Definition 5 ([19]).. Let $N = \{1, \ldots, i, \ldots, n\}$ be the time series set, $Y = \{y_1, \ldots, y_i, \ldots, y_n\}$ be the outcome set in the time line, and $\pi_{n,i}$ be the relative weight function of outcome y_i. The reference point r_{n+1} in period $n+1$ can be calculated in the following form.

$$r_{n+1} = \rho + \sum_{i=1}^{n} \pi_{n,i} y_i \tag{6}$$

where ρ is a built-in parameter, the estimate value of ρ in [19] is 5.2. And $\sum_{i=1}^{n} \pi_{n,i} = 1$, $\pi_{n,i}$ represents the weight information of $i-th$ time, which can be expressed as a weighting function $\mathbf{w}(\frac{1}{n})$ and Eq. (6) can be in the following form as well.

$$r_{n+1} = \rho + \sum_{i=1}^{n} \left[\mathbf{w}\left(\frac{i}{n}\right) - \mathbf{w}\left(\frac{i-1}{n}\right) \right] y_i \tag{7}$$

where the weight function $\mathbf{w}(\cdot)$ can be any continuous and increasing function with $\mathbf{w}(0) = 0$ and $\mathbf{w}(1) = 1$. Through the experiments in [19], the specific form of $\mathbf{w}(\cdot)$ is represented in Eq. (8).

$$\mathbf{w}(x) = e^{-(-Inx)^\gamma / \xi} \tag{8}$$

where the value of γ is 0.2 and 0.26, the value of ξ is 0.9, 1.7 and 2.1, from Fig. 2, it can be intuitively see that the shape of $\mathbf{w}(x)$ is reverse S-shaped, with steep sides and quite flat in the middle and the parameter γ determines the curvature of $\mathbf{w}(x)$, while the parameter ξ controls the elevation of $\mathbf{w}(x)$.

Definition 6 ([13]).. Let m^+be the number of the states of weak gains, N be the total number of states and $m^- = N - m^+$ be the number of the states of strict loss. The decision weight function $w(s_i, f, h)$ assigned to state s_i when f is evaluated from h in PT^3 can be represented as follows.

$$w(s_i,f,h) = \begin{cases} w^+(\pi_i) & i = N \\ w^+\left(\sum\limits_{j \geq i} \pi_j\right) - w^+\left(\sum_{j>i} \pi_j\right) & m^- + 1 \leq i < N \\ w^-\left(\sum\limits_{j \leq i} \pi_j\right) - w^-\left(\sum_{j<i} \pi_j\right) & 1 \leq i \leq m^- \\ w^-(\pi_i) & i = 1 \end{cases} \tag{9}$$

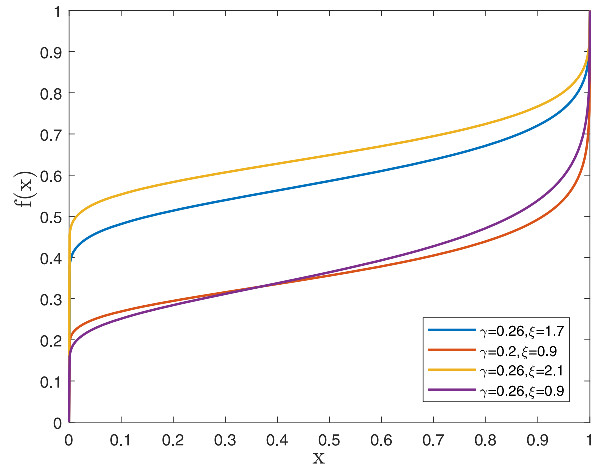

Fig. 2. Curve of $\mathbf{w}(x)$ where $x \in [0, 1]$.

where $w^+(\cdot)$ is the probability weight function for the gain domains and $w^-(\cdot)$ is the probability weight function for loss domains, according to the Ref. [11], the form of $w^+(\cdot)$ and $w^-(\cdot)$ are denoted as follows.

$$w^+(\pi_i) = \left(\frac{\pi^\varepsilon}{\pi^\varepsilon + (1-\pi)^\varepsilon} \right)^{1/\varepsilon} \tag{10}$$

$$w^-(\pi_i) = \left(\frac{\pi^\delta}{\pi^\delta + (1-\pi)^\delta} \right)^{1/\delta} \tag{11}$$

where ε and δ are model parameters controlling the shape of the weighting function.

Remark 2. For any f, h pair, there is a weak gain in a state s_i if $f(s_i) \geq h(s_i)$, and a strict loss if $f(s_i) < h(s_i)$.

Definition 7 ([13]).. Let M be the set of weak gains, G denotes the strict loss. The prospect value of PT^3 can be expressed as follows.

$$V(f,h) = \sum_{i \in M} v(f,h) \times w(s_i,f,h) - \sum_{i \in G} v(f,h) \times w(s_i,f,h) \tag{12}$$

Thus, the function $V(f, h)$ can be applied to construct the prospect value matrix of each DM.

2.3. The extended MULTIMOORA method

In this subsection, the major part in MULTIMOORA method is presented. Furthermore, the SMAA method [39] and BC method [37,52] are applied to replace the dominance theory to determine the final ranking results, where the BC method is named and proposed by the French mathematician and physicist Jean-Charles de Borda [53], which is inspired the voting paradox first introduced by Condorcet [54]. BC method can be regarded as the generalization of the majority-voting rule. To a certain degree, it can be defined as a mapping from individuals ranking results to the integrated ranking result to the most relevant decision.

(1) ***Ratio System***
There are the decision matrix $X = (x_{ij})_{m \times n}$ for alternative set $A = \{a_1, a_2, \ldots, a_m\}$ and the criteria set $c = \{c_1, c_2, \ldots, c_n\}$ with its corresponding weight set $wc = \{wc_1, wc_2, \ldots, wc_n\}$ and $\sum_{j=1}^{n} wc_j = 1$, where x_{ij} is the evaluation value of alternative a_i on the criteria c_j. Then

standardization X is completed in the form [55].

$$x_{ij}^{*}=\frac{x_{ij}}{\sqrt{\sum_{i=1}^{m}x_{ij}^{2}}} \tag{13}$$

After that,

$$y_{i}^{*}=\sum_{j=1}^{g}wc_{j}x_{ij}^{*}-\sum_{j=g+1}^{n}wc_{j}x_{ij}^{*} \tag{14}$$

where g and $n-g$ respectively denote the numbers of benefit criteria and cost criteria, the parameter y_i^* represents the normalized evaluation of alternative a_i related to all objectives. The optimal alternative a_{RS}^* under RS can be acquired as

$$a_{RS}^{*}=\{a_i|\max_{i} y_i^{*}\} \tag{15}$$

(2) ***Reference Point Theory***
The first step is to find the reference point for each alternative using the standardized data obtained by Eq. (13), then the reference point r_j can be defined as follows.

$$r_j=\begin{cases}\max\limits_{j} x_{ij}^{*} & j\le g\\ \min\limits_{j} x_{ij}^{*} & j>g\end{cases} \tag{16}$$

Based on this, a Tchebycheff Min–Max metric to calculate the deviation between the assessment value of each alternative and the reference point in Eq. (17) as below.

$$d_i=\{\max_{j} wc_j|r_j-x_{ij}^{*}|\} \tag{17}$$

where $i\in[1,n]$ and the optimal alternative in reference point theory can be obtained as

$$a_{RP}^{*}=\{a_i|\min_{i} d_i\} \tag{18}$$

(3) ***Full Multiplicative Form Method***
The utility value of the alternative can be written as follows.

$$U_i=\frac{\prod_{j=1}^{g}(x_{ij}^{*})^{wc_j}}{\prod_{j=g+1}^{n}(x_{ij}^{*})^{wc_j}} \tag{19}$$

where $\prod_{j=1}^{g}x_{ij}^{*}$ stands for the product of evaluation value of all benefit criteria and $\prod_{j=g+1}^{n}x_{ij}^{*}$ is the product of the evaluation values of all cost criteria. After that, the optimal alternative under the MFM method can be expressed as $a_{MFM}^{*}=\{a_i|\max_i U_i\}$.

(4) ***The BC method***
After the establishment of the ranking results of the three subordinate methods, it is need to aggregate these results to obtain the final rankings, all of these methods in MULTIMOORA are non-correlated objectives [56]. The original dominance theory determines the overall rankings by integrating the subordinate rankings, when the number of alternatives is in a small scale, the original dominant theory can quickly obtain the overall rankings. However, in the large amount of alternatives, its operation efficiency will reduce. Furthermore, it fails to consider the utility value of each alternative in the three methods. Based on these analysis, BC method as a substitute for aggregation of the results. The vector normalization method in Eq. (13) is used to normalize the three sub utility values, which proved to be the suitable choice for normalization [55]. The aggregation process can be seen in Eq. (20)

$$bc_i=\mathbf{n}(a_{RS}^{i})-\mathbf{n}(a_{RP}^{i})+\mathbf{n}(a_{MFM}^{i}) \tag{20}$$

where $\mathbf{n}(\cdot)$ denotes the normalized utility values, a_{RS}^{i}, a_{RP}^{i} and a_{MFM}^{i} are the values of alternative x_i under the three utility functions. The larger value of the bc_i indicates that the corresponding alternative has the better performance.

(5) ***SMAA method***
There are two feasible space of W and X, where W is the space of criteria weights, while $X_{m\times n}$ presents the evaluation matrix of alternatives under a set of criteria. Firstly the ranking of alternative x_i can be obtained in Eq. (21).

$$rank\left(x_i,\varphi,w\right)=1+\sum_{k\neq i}^{m}\boldsymbol{\rho}\left(u\left(\varphi_{(x_k)},w\right)>u\left(\varphi_{(x_i)},w\right)\right) \tag{21}$$

where φ represents the stochastic value of alternative on a criterion and w denotes a random giving criterion weight value, satisfying the uniform distribution in $[0,1]$ and $\sum w_j=1$, $u(\cdot)$ is the related utility function of alternative, where $u\left(\varphi_{(x_i)},w\right)=\sum_{j=1}^{n}w_j\varphi_{ij}$. $\boldsymbol{\rho}(\cdot)$ is a binary function, if $u\left(\varphi_{(x_k)},w\right)>u\left(\varphi_{(x_i)},w\right)$, then $\boldsymbol{\rho}(\cdot)=1$, else $\boldsymbol{\rho}(\cdot)=0$. Then $W_i^r(\varphi)=\{w\in W|rank(x_i,\varphi,w)=r\}$ is the set of rank weights making alternative x_i in the rank r.
There are three measurements of SMAA to evaluate the final rankings, the rank acceptability indexes, the central weight vectors and the confidence factors. Let b_i^r be the rank acceptability index of alternative x_i being on $r-th$ position. Where the expression of b_i^r $b_i^r\in[0,1]$ can be written as follows.

$$b_i^r=\int_{\varphi\in X}f_X(\varphi)\int_{w_i\in W_i^r(\varphi)}f_W(w)\,dwd\varphi \tag{22}$$

where f_X and f_W are the probability density functions of φ and w.
Let $w_i^{central}$ be the central weight vector of alternative x_i being on the first rank The value of $w_i^{central}$ is displayed as.

$$w_i^{central}=\frac{1}{b_i^1}\int_{\varphi\in X}f_X(\varphi)\int_{w_i\in W_i^1(\varphi)}f_W(w)\,wdwd\varphi \tag{23}$$

where the rank acceptability index b_i^1 indicates x_i is on the first rank, and $W_i^1(\varphi)=\{w\in W|rank(x_i,\varphi,w)=1\}$.
The confidence factor $p_i^{central}$ stands for the possibility of alternative x_i in the first position with determined central weight vector, which is shown as follows.

$$p_i^{central}=\int_{\varphi\in X:rank(x_i,\varphi,w)=1}f_X(\varphi)\,d\varphi \tag{24}$$

The SMAA-MULTIMOORA method is based on Monte Carlo simulation to calculate the results of the measurements, the detail procedures are illustrated in Algorithm 1.

3. Solution procedures for assessment of emergency response plan

In this section, we develop a novel emergency response plans evaluation method based on GDM. Firstly, the IT2FS-PT^3 method is represented, then we integrate the extended MULTIMOORA method, and the group consensus is considered as well by designing a convergent iterative algorithm to gain the consentaneous group decision result. Finally, the solution process of emergency response plan selection is illustrated. In the evaluation process depicted in Fig. 3, the linguistic terms are quantified as the centroid intervals of IT2FSs through KM algorithm, then interval-based decision matrix of each DM is constructed. In the PT^3 framework, we input the concept of time series to predict the reference points in different periods for the setting of dynamic reference points, which is line with the timeliness of emergency

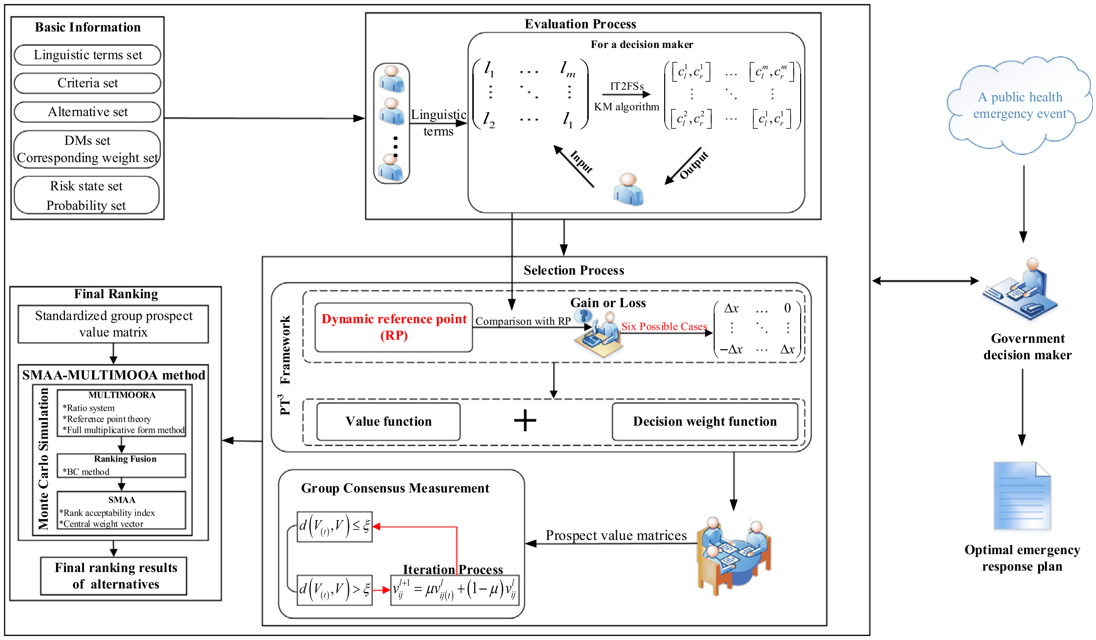

Fig. 3. Construction of a consensus prospect value matrix.

Table 1
Possible cases of Δx.

Possible Cases	Δx	For Benefit/ Neutral Criteria		For Cost Criteria	
		Gain	Loss	Gain	Loss
case1: $x_{ij}^l < x_{ij}^r < h_j^l < h_j^r$	$h_j^l - 0.5(x_{ij}^r + x_{ij}^l)$		✓	✓	
case2: $x_{ij}^l < h_j^l < x_{ij}^r < h_j^r$	$(h_j^l - x_{ij}^l)^2/2(x_{ij}^r - x_{ij}^l)$		✓	✓	
case3: $h_j^l < x_{ij}^l < x_{ij}^r < h_j^r$	0				
case4: $h_j^l < x_{ij}^l < h_j^r < x_{ij}^r$	$-(h_j^r - x_{ij}^r)^2/2(x_{ij}^r - x_{ij}^l)$	✓			✓
case5: $x_{ij}^l < h_j^l < h_j^r < x_{ij}^r$	$0.5(h_j^l + h_j^r) - 0.5(x_{ij}^l + x_{ij}^r)$	✓			✓
case6: $h_j^l < h_j^r < x_{ij}^l < x_{ij}^r$	$h_j^r - 0.5(x_{ij}^l + x_{ij}^r)$	✓			✓

response plans. Simultaneously, there are six possible cases of the relationship between interval-based evaluation information and the related reference point, shown in Table 1. Thereafter, we construct the decision matrix in the level of reaching group consensus, and the final ranking results can be determined by the extended MULTIMOORA method.

In this study, we assume that all the DMs make their judgments on the aspect of emergency response plans evaluations by using the same linguistic terms set.

3.1. Description of IT2FS-PT^3 based emergency response plan evaluation

We can see that the assessments for emergency response plans can be regarded as a MCGDM problem in the uncertain and fuzzy environment. First, the relative parameters are expressed as follows.

- $D = \{d_1, d_2, \ldots, d_T\}$: the set of DMs from hospitals, public health departments and other related sectors, the corresponding weight of experts λ_t satisfying $\sum_{t=1}^{T} \lambda_t = 1$.
- $A = \{a_1, a_2, \ldots, a_I\}$: the set of I emergency response plans (alternatives) needs to find the optimal one in an emergency event.
- $C = \{c_1, c_2, \ldots, c_J\}$: the set of J criteria is served as evaluation indexes of emergency events, which can be divided in 3 types: the beneficial criteria, the cost criteria and the neutral criteria and w_j is the weight of criterion c_j, satisfying $w_j \in [0, 1]$ and $\sum_{j=1}^{J} w_j = 1$.
- $L = \{l_1, l_2, \ldots, l_M\}$: the set of linguistic terms, these linguistic terms are expressed in the form of IT2FSs in this proposed model.
- $S = \{s_1, s_2, \ldots, s_N\}$: the set of n states of a public health emergency event, where s_n is the *n-th* state. Generally, the classification of S can be obtained by the previous similar emergency events.
- $P = \{p_1, p_2, \ldots, p_N\}$: the probability set for the state S, where $p_n \in [0, 1]$ and $\sum_{n=1}^{N} p_n = 1$, p_n means the probability of state s_n occurring in the future.
- $X = (x_{ij})_{I\times J}$: the decision making matrix from a DM, where x_{ij} denotes the value of alternative a_i under the criteria c_j.
- $O = \{o_1, o_2, \ldots, o_W\}$: the time line set for an emergency event, where length$(O) = W$, length$(o_1) = \cdots =$ length(o_W) and o_w stands for the *w-th* time period.
- $H = \{H^1, H^2, \ldots, H^W | H^w = H^w(s_1), H^w(s_2), \ldots, H^w(s_N)\}$: the uncertain reference point vector set, where $H^w(s_n)$ means the reference point vector in the state s_n at period o_w and can be expressed as $H^w(s_n) = \left(h^w(s_n)_1, h^w(s_n)_2, \ldots, h^w(s_n)_J\right)$.
- $V = \left\{V_{(1)}, V_{(2)}, \ldots, V_{(T)} | V_{(t)} = \left(v_{ij}\right)_{(t)}^{I\times J}\right\}$: the illustration of value matrix set from DMs, where $V_{(t)}$ is the prospect value matrix from DM d_t and $v_{ij(t)}$ presents the prospect value of alternative a_i under the criteria c_j of DM d_t.

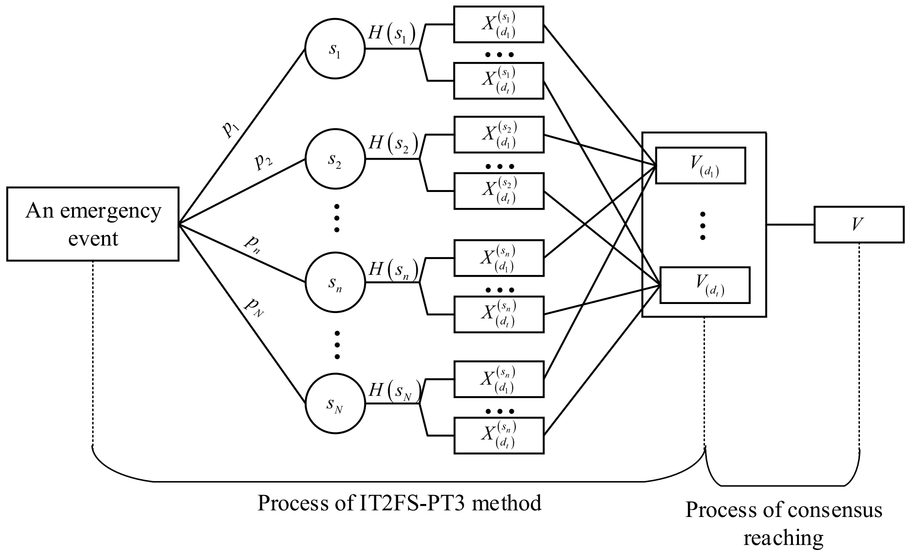

Fig. 4. Overall process behind the proposed model.

Remark 3. In the process of a real-world emergency response plans evaluation, due to the complexity and inadequate information of the emergency event, the selection of evaluation indexes is supposed to be summarized from all relative aspects. These indexes are abstract and cannot be explained by numeric entries [28,42]. Consequently, the expressions of linguistic terms are more reasonable for DM making assessments. When for the setting of parameters α, σ, ε and δ of PT^3 mentioned in Section 2.2, We refer the values of these parameters in Ref. [11], the median exponent of value function $\alpha = 0.88$, $\sigma = 2.25$ and the median values of $\varepsilon = 0.61$, $\delta = 0.69$.

In this paper, we develop a novel IT2FS-PT^3 with the extended MULTIMOORA method to evaluate and select the optimal emergency response plan. Firstly, the process of the IT2FS-PT^3 method in an emergency event can be described in Fig. 4, which shows in detail the construction of the prospect decision matrix of each DM in different states, then forms the consensus reached prospect decision matrix.

In the process of group consensus reaching, the group prospect value matrix can be obtained by aggregating the single DM's prospect value matrix through the additive weighted aggregation (AWA) operator, which can be expressed as follows.

$$V = \sum_{t=1}^{T} \lambda_t V_{(t)} \tag{25}$$

where λ_t denotes the weight of t-th DM and $V_{(t)}$ is the prospect value of t-th DM. To measure the level of similarity of prospect value matrix between the individuals and the group, the distance function is expressed as.

$$d\left(V_{(t)}, V\right) = \frac{1}{mn}\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left|v_{ij(t)} - v_{ij}\right|^2\right)^{1/2} \tag{26}$$

where $d\left(V_{(t)}, V\right)$ stands the similarity degree of $V_{(t)}$ and V. It is worth noting that $d\left(V_{(t)}, V\right)$ satisfies the attributes of general distance function as: $0 \le d\left(V_{(t)}, V\right) \le 1$, $d\left(V_{(t)}, V\right) = d\left(V, V_{(t)}\right)$ and $d\left(V, V\right) = 0$.

Definition 8.

Let η be the threshold of acceptable consensus level, which can be determined by DMs in advance.

$$d\left(V_{(t)}, V\right) \le \eta \tag{27}$$

If $\forall t \in \{1, \ldots, T\}$, Eq. (27) is satisfied, which means that the group has reached consensus.

Definition 9. If $\exists t \in \{1, \ldots, T\}$ such that $d\left(V_{(t)}, V\right) > \eta$, then matrices $V_{(t)}$ and V are of unacceptable similarity. The Eq. (28) is given to reconstruct these matrices in a convergent iterative form.

$$v_{ij(t)}^{l+1} = \begin{cases} \mu v_{ij(t)}^{l} + (1-\mu) v_{ij}^{l} & d\left(V_{(t)}, V\right) > \eta \\ v_{ij(t)}^{l} & otherwise \end{cases} \tag{28}$$

where μ is a constant satisfied $0 < \mu < 1$ and l be the l-th of iterative time.

Theorem 1. *Under the above hypotheses, there is* $d\left(V_{(t)}^{l+1}, V^{l+1}\right) \le d\left(V_{(t)}, V\right)$.

Proof. if $d\left(V_{(t)}, V\right) > \eta$, then

$$\begin{aligned} d\left(V_{(t)}^{l+1}, V^{l+1}\right) &= \frac{1}{mn}\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left|v_{ij(t)}^{(l+1)} - v_{ij}^{(l+1)}\right|^2\right)^{1/2} \\ &= \frac{1}{mn}\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left|v_{ij(t)}^{(l+1)} - \sum_{k'=1}^{t}\lambda_{(t')} v_{ij(t')}^{(l+1)}\right|^2\right)^{1/2} \\ &= \frac{1}{mn}\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left|\sum_{t'=1}^{t}\lambda_{(t')}\left(v_{ij(t)}^{(l+1)} - v_{ij(t')}^{(l+1)}\right)\right|^2\right)^{1/2} \end{aligned}$$

From Eq. (28), we have $v_{ij(t)}^{(l+1)} - v_{ij(t')}^{(l+1)} = \mu v_{ij(t)}^{(l)} + (1-\mu) v_{ij}^{(l)} - \left(\mu v_{ij(t')}^{(l)} + (1-\mu) v_{ij}^{(l)}\right)$. Then:

$$\begin{aligned} d\left(V_{(t)}^{l+1}, V^{l+1}\right) &= \frac{1}{mn}\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left|\sum_{t'=1}^{t}\lambda_{(t')}\left(\mu v_{ij(t)}^{(l)} - \mu v_{ij(t')}^{(l)}\right)\right|^2\right)^{1/2} \\ &= \frac{\mu}{mn}\left(\sum_{i=1}^{m}\sum_{j=1}^{n}\left|v_{ij(t)}^{(l)} - v_{ij}^{(l+1)}\right|^2\right)^{1/2} \\ &= \mu d\left(V_{(t)}^{l}, V^{l}\right) \le d\left(V_{(t)}^{l}, V^{l}\right) \end{aligned}$$

which completes the proof of Theorem 1.

3.2. The IT2FS-PT^3 integrated with the extended MULTIMOORA method

For this section, we focus on the main model proposed in this paper, in what follows, the specific procedures are given below.

(1) ***Data Processing***
In the evaluation system, there are three types of criteria: the benefit criteria, the neural criteria and the cost criteria. For these types of criteria, we assign different parameter values in the subsequent value functions. Then, the initial linguistic evaluation matrix given by each DM is transformed into IT2FSs-based decision matrix according to the given UMF and LMF of each linguistic term. Through the KM algorithm mentioned in Section 2, we can calculate the centroids of the IT2FSs. Supposed that, the values of linguistic terms follow uniform distribution in the centroid intervals of the IT2FSs, then the expression of linguistic terms is.

$$l_m = \left[c_l^m, c_r^m, g\left(x\right)\right] \tag{29}$$

where l_m is the m-th linguistic term, for instance, the linguistic term "Low" can be expressed as $[c_l^{\text{low}}, c_r^{\text{low}}, g\left(x\right)]$. $g(x)$ is the corresponding probability density function expressed as follows.

$$g(x) = \begin{cases} \frac{1}{c_r^m - c_l^m} & c_l^m \le x \le c_r^m \\ 0 & \text{otherwise} \end{cases} \tag{30}$$

where x is an arbitrary value satisfied $x \in [c_l^m, c_r^m]$.

(2) ***Determination of the value function from DMs***
According to the psychological characteristics of each DM, we give the corresponding value functions and the determination of the parameters is based on the research in Ref. [11]. The value functions of the benefit criteria and neutral criteria are expressed as follows.

$$v\left(\Delta x_{ij(t)}^{s_n}\right) = \begin{cases} \left(-\Delta x_{ij(t)}^{s_n}\right)^{\alpha} & x_{ij(t)}^{s_n} \ge h(s_n)_j \quad \text{Gain} \\ -\sigma\left(\Delta x_{ij(t)}^{s_n}\right)^{\alpha} & x_{ij(t)}^{s_n} < h(s_n)_j \quad \text{Loss} \end{cases} \tag{31}$$

and the value function of the cost criteria can be expressed as.

$$v\left(\Delta x_{ij(t)}^{s_n}\right) = \begin{cases} \left(\Delta x_{ij(t)}^{s_n}\right)^{\alpha} & x_{ij(t)}^{s_n} \le h(s_n)_j \quad \text{Gain} \\ -\sigma\left(-\Delta x_{ij(t)}^{s_n}\right)^{\alpha} & x_{ij(t)}^{s_n} > h(s_n)_j \quad \text{Loss} \end{cases} \tag{32}$$

where $\Delta x_{ij(t)}^{s_n} = h(s_n)_j - x_{ij(t)}^{s_n}$ and $x_{ij(t)}^{s_n}$ denotes t-th DM's assessment result of the i-th emergency response plan under the j-th criterion in the state s_n, $h(s_n)_j$ is the reference value of the j-th criterion in the state s_n. And for the benefit and cost criteria, the loss aversion parameter σ is 2.55, α is 0.88, while for the neural criteria, $\sigma = 1$ and $\alpha = 0.88$.
Simultaneously, considering the features of public health emergency events affected by time series. Wuhan switched from a high risk area in March into a low risk area in April. Hence, the time factor is supposed to taken into consideration for the formation and updating of dynamic reference point. We introduce the prediction method of reference point formation in the time line referred in [19] as follows.

$$h\left(s_n\right)_j^w = \rho + \sum_{w=1}^{W}\left[f\left(\frac{w}{W}\right) - f\left(\frac{w-1}{W}\right)\right]\cdot y_w \tag{33}$$

where $f(\cdot)$ is the continuously increasing function of the variable in the interval [0,1], satisfying $f(0) = 0$ and $f(1) = 1$. the form of $f(\cdot)$ is shown in Eq. (8). And y_w is the mean vector of DMs for all criteria in the w-th time period, which can be written as.

$$y_w = \mathbf{avg}\left(\sum_t \lambda_t x_{ij(t)}^{s_n}\right) \tag{34}$$

where $\mathbf{avg}(\cdot)$ is applied to calculate the average value of the column in the matrix calculations.
Therefore, considering that $x_{ij(t)}^{s_n}$ and $h(s_n)_j$ are interval numbers, there are six possible situations for Δx, as shown in the Table 1, and the procedures of these cases are illustrated in Appendix A.

(3) ***Calculation for the decision weight function***
The decision weight function of the value of emergency response plan in the criterion expressed as below.

$$w\left(s_n, x_{ij(t)}^{s_n}, h_j\left(s_n\right)\right) = \begin{cases} w^+\left(p_n\right) & n = N \\ w^+\left(\sum_{o\ge n} p_n\right) - w^+\left(\sum_{o>n} p_n\right) & m^- + 1 \le i \le N \\ w^-\left(\sum_{o\le n} p_n\right) - w^-\left(\sum_{o<n} p_n\right) & 1 < i \le m^- \\ w^-\left(p_n\right) & n = 1 \end{cases} \tag{35}$$

where $w^+\left(p_n\right)$ and $w^-\left(p_n\right)$ in Ref. [11] can be expressed as follows.

$$w^+\left(p_n\right) = \frac{{p_n}^{\varepsilon}}{\left({p_n}^{\varepsilon} + \left(1 - p_n\right)^{\varepsilon}\right)^{1/\varepsilon}} \tag{36}$$

and

$$w^-\left(p_n\right) = \frac{{p_n}^{\delta}}{\left({p_n}^{\delta} + \left(1 - p_n\right)^{\delta}\right)^{1/\delta}} \tag{37}$$

where the value of ε is 0.61 and δ is 0.69, which are the same settings in Ref. [11].

(4) ***Construction of the prospect value matrix of each DM***
Through the calculation of Eq. (38), we can obtain the prospect value of each DM for the emergency response plans in different criteria.

$$V_{(t)} = \sum_{i\in M} v\left(x_{ij(t)}^{s_n}\right) \times w^+\left(p_n\right) - \sum_{i\in G} v\left(x_{ij(t)}^{s_n}\right) \times w^-\left(p_n\right) \tag{38}$$

where $V_{(t)}$ is the prospect value matrix from DM d_t.

(5) ***The group prospect matrix in an admissible consensus level***
After attaining the prospect matrices of individual DMs, AWA operators is used to formalize the group prospect matrix as exhibited in Eq. (39).

$$V^* = \sum_{t=1}^{T} \lambda_t V_{(t)} \tag{39}$$

where V^* is the group prospect matrix, if the obtained group prospect matrix does not satisfy the acceptable consensus condition given in Eq. (27), then Eq. (28) is applied to recalculate the group prospect matrix until satisfying the group consensus. Thereafter, Eqs. (40) and (41) are applied to standardize V^*.

$$v_{ij}^* = \frac{v_{ij}^* - \min_i v_{ij}^*}{\max_i v_{ij}^* - \min_i v_{ij}^*} \tag{40}$$

and

$$v_{ij}^* = \frac{\max_i v_{ij}^* - v_{ij}^*}{\max_i v_{ij}^* - \min_i v_{ij}^*} \tag{41}$$

Table 2
Risk classification standard.

	Definition	Explanation in detail
s_1	High Risk Area	The cumulative number of cases exceeds 50, and a cluster of epidemics occurred within 14 days
s_2	Medium Risk Area	Newly confirmed cases within 14 days, the cumulative number of confirmed cases does not exceed 50, or the cumulative number of confirmed cases exceeds 50, and no cluster epidemic occurs within 14 days
s_3	Low Risk Area	No confirmed cases or no new confirmed cases for 14 consecutive days

Table 3
The criteria for the assessment of emergency response plans.

Criterion	Definition	Explanation in detail
c_1	Time	The most important index in emergency response plan evaluation, it is required to solve emergency events in time to reduce the damage
c_2	Attendance of Medical Staff	The required number of medical staff in an emergency response plan
c_3	Economic Impact	Cost of the emergency response plan for handling public health emergency events
c_4	Social Influence	The positive impact on society after taking emergency response plans to resolve emergency events
c_5	Resource Consumption	The consumption medical supplies in the public health emergency events
c_6	Transportation Security	Implement blockade management on epidemic areas When the pandemic happened
c_7	Flexibility	The emergency response plan should be dynamically adjustable for the uncertainty of emergency events

where Eq. (40) is for the benefit criteria and Eq. (41) is for the cost criteria.

(6) ***Evaluation results in the extended MULTIMOORA method*** Substitute the consensus reached group prospect matrix into the extended MULTIMOORA method at the aim of making the sequence for these emergency response plans. Firstly, determine the feasible criteria weights space W in this proposed model, it is assumed that DMs have the same preference for each criterion, which implies the weight space can be expressed as $W = \left\{w_j \geq 0 | \sum_{j=1}^{J} w_j = 1\right\}$, where w_j is a random number generated by a normal distribution. Secondly, calculate the rankings of the three utility functions RS in Eq. (15), RP in Eq. (18) and FMF in Eq. (19) of MULTIMOORA method with the weight w_j $(j = 1, \ldots, J)$, then BC method in Eq. (20) is applied to aggregate the three utility values. Finally, Monte Carlo simulation runs 1000 times to calculate the integrals, thereafter, b_i^r in Eq. (22), $w_i^{central}$ in Eq. (23) can be obtained.

(7) ***The final ranking of emergency response plan*** In the end, we can obtain the final ranking of these emergency response plans. The whole algorithm of this proposed method can be seen in Algorithm 1 given below.

4. Case study

On the aim of explaining the validity and feasibility of the proposed model, this section exhibits the real case, that is, the eruption of infectious disease, adapted from COVID-19 that occurred in Wuhan, China.

4.1. Background description

The COVID-19 as a potential deadly coronavirus has caused a level of global illness unseen in numbers and rapidity since it occurred in late 2019. Through the report of National Health Commission of People's Republic of China, there are three potential states of risk levels $S = \{s_1, s_2, s_3\}$ in COVID-19, i.e. s_1: high risk area, s_2:medium risk area and s_3: low risk area. The specific explanations of these status is shown in Table 2. Simultaneously, we collect the statistics of cumulative confirmed cases from Wuhan Municipal Health Commission website (wjw.wuhan.gov.cn) on March 5th, March 24th, April 7th and April 28th, which the corresponding data is shown in Appendix A. Fig. 5 presents the distribution of Wuhan epidemic risk level map at four time points, which can be vividly seen that the change of risk level is affected by time factors, and Fig. 5 also indicates the rationality of setting three states in the evaluation of an emergency event.

Table 4
Linguistic evaluation terms and their upper and lower membership functions.

Linguistic terms	UMF	LMF
Very Unimportant (VUI)	(0,0.1,0.1,0.2,1)	(0,0.1,0.1,0.2,0.8)
Unimportant (UI)	(0.1,0.3,0.3,0.5,1)	(0.1,0.3,0.3,0.5,0.8)
Slightly Important (SI)	(0.3,0.5,0.5,0.7,1)	(0.3,0.5,0.5,0.7,0.8)
Important (I)	(0.5,0.7,0.7,0.9,1)	(0.5,0.7,0.7,0.9,0.8)
Very Important (VI)	(0.8,0.9,0.9,1,1)	(0.8,0.9,0.9,1,0.8)

Meanwhile, it can be known that Wuhan successfully converted from full high risk areas to full low risk areas in nearly about two months owing to the effective prevention and controllability of the government, we set the time set $O = \{o_1, o_2, o_3\}$, the interval between them is set to 14 days. In the time point o_1 the corresponding states is s_1, in the time point o_1 is connected with the state s_2 and the state in the time point o_3 is s_3. Accordingly, the corresponding probability of the above states are designed as follows: $p_1 = 0.2$, $p_2 = 0.3$ and $p_3 = 0.5$. Suppose that there are 3 representative DMs $D=\{d_1, d_2, d_3\}$ from hospitals, disease control and prevention centers and other clinical institutions their corresponding weights are set as $\lambda_1 = 0.4$, $\lambda_2 = 0.3$, $\lambda_3 = 0.3$, 5 emergency response plans $A = \{a_1, a_2, a_3, a_4, a_5\}$ for DMs to make evaluations. Considering the complexity of emergency response plans evaluation, we select 7 criteria $C = \{c_1, c_2, c_3, c_4, c_5, c_6, c_7\}$ in the report of National Health Commission of People's Republic of China, displayed in Table 3. And c_1, c_2, c_3 and c_5 are the cost criteria, c_4 and c_7 are the benefit criteria, c_6 is the neutral criterion. In general, the value of the consensus threshold level η is 0.05, and the parameter coefficient μ during the iteration process is set as 0.5.

4.2. Procedures of this proposed model

Some required conditions and specific solution steps are displayed in this section. Table 4 exhibits the linguistic terms set and

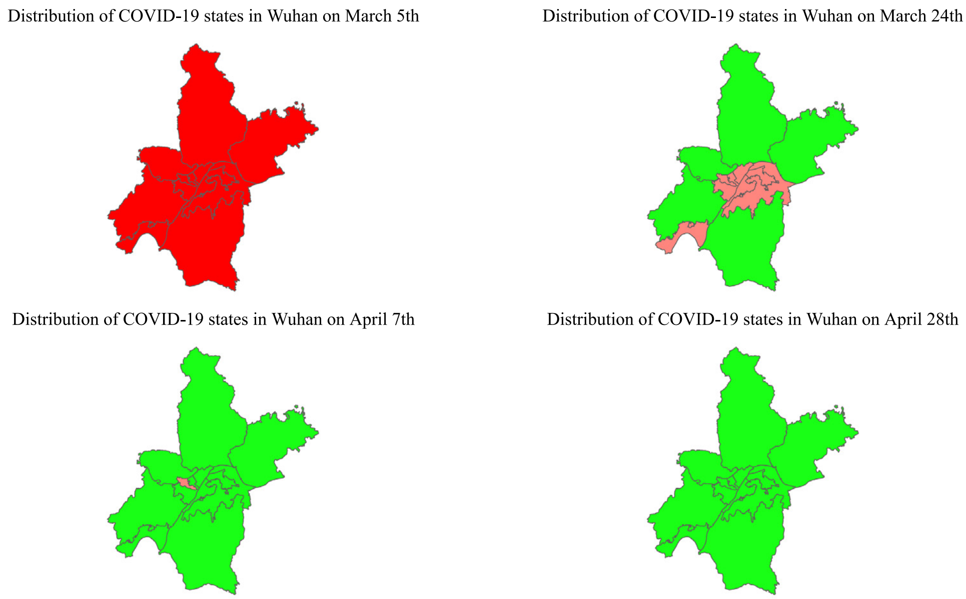

Fig. 5. Distribution of COVID-19 states in Wuhan (Full high risk areas(marked in red) on March 5th; 8 medium risk areas(marked in light red) and 5 low risk areas(marked in green) on March 24th;1 medium risk area and 12 low risk areas on April 7th;Full low risk areas on April 28th).

Table 5
The linguistic evaluation information of DMs in the state of s_1.

		c_1	c_2	c_3	c_4	c_5	c_6	c_7
	a_1	SI	I	UI	VI	UI	VI	SI
	a_2	I	SI	I	I	UI	SI	VI
DM_1	a_3	I	UI	VUI	SI	SI	UI	I
	a_4	UI	I	SI	VI	SI	I	VI
	a_5	VI	VUI	SI	SI	I	UI	I
	a_1	I	UI	SI	I	SI	I	I
	a_2	VI	I	I	VI	VUI	UI	SI
DM_2	a_3	SI	UI	UI	I	UI	SI	I
	a_4	SI	I	UI	I	SI	I	VI
	a_5	I	SI	I	SI	SI	SI	I
	a_1	SI	SI	UI	I	VUI	SI	UI
	a_2	I	UI	SI	VI	UI	SI	I
DM_3	a_3	VI	SI	UI	I	UI	I	VI
	a_4	VUI	VI	SI	I	I	SI	UI
	a_5	I	SI	UI	I	SI	VUI	VI

the relative IT2FS MF. The assessment information of DMs in the state of s_1 is displayed in Table 5, and the linguistic evaluation information in other states s_2 and s_3 can be seen in Appendix A.

Step 1. ***Linguistic evaluation information process***

According to Table 4, KM algorithm is used to calculate the centroid intervals of each linguistic term, follows as: VUI: [0.0963,0.1037], UI:[0.2926,0.3074], SI:[0.4926,0.5074], I:[0.6926,0.7074] and VI:[0.8963,0.9037]. Thereafter, the linguistic evaluation information of DMs can be transformed into the interval-based decision matrices.

Step 2. ***Calculation of the prospect values***

Firstly, in the s_1 state, let the mean vector of each criterion be the reference point vector $h(s_1)^{o_1}$. According to Eq. (34), $h(s_1)^{o_1}$ is equal to y_1, then following by the Eq. (33), $h(s_2)^{o_2}$ can be obtained as $h(s_2)^{o_2} = \rho + f(1) \cdot y_1$, and $h(s_3)^{o_3}$ expressed as $h(s_3)^{o_3} = \rho + f\left(\frac{1}{2}\right) \cdot y_1 + \left[f(1) - f\left(\frac{1}{2}\right)\right] \cdot y_2$, where y_1 and y_2 are the mean vectors of DMs for criteria in the o_1 time and o_2 time respectively. The value of γ and ξ are 0.26 and 1.7. The estimation of ρ value in the research [19] is 5.2, the magnitude of variables in [19] is 10^3, while in this proposed study the magnitude of variables is between -1 and 0, then the value of ρ is set as 0.0052. Thus the reference vector $h(s_1)^{o_1}$, $h(s_2)^{o_2}$ and $h(s_3)^{o_3}$ can be denoted in the following form.

$$h(s_1)^{o_1} = ([0.61, 0.63], [0.49, 0.50], [0.42, 0.44], [0.71, 0.72], \times [0.41, 0.42], [0.51, 0.52], [0.69, 0.70])$$

$$h(s_2)^{o_2} = ([0.62, 0.63], [0.49, 0.51], [0.43, 0.44], [0.71, 0.72], \times [0.41, 0.42], [0.51, 0.53], [0.69, 0.70])$$

$$h(s_3)^{o_3} = ([0.59, 0.60], [0.52, 0.53], [0.44, 0.45], [0.69, 0.70], \times [0.42, 0.43], [0.52, 0.53], [0.67, 0.69])$$

Then, according to the six possible situations shown in Table 1, the corresponding Δx value obtained by comparing the reference points with the DMs' evaluation values. Thus, the gain or loss situation of each DM can be obtained. Table 6 exhibits the DM's evaluation values in state s_1, the situations in state s_2 and state s_3 are represented in Appendix A. For better comprehension, here is an example: in state s_1, the linguistic evaluation term given by DM_1 for emergency response plan a_1 under the benefit criterion c_4 is VI:[0.8963,0.9037], and $h(s_1)^{o_1}(4) = [0.7056, 0.7184]$, which in accordance with **case 6**, the assessed value is acquired as: $0.7184 - 0.5(0.8963 + 0.9037) = -0.1816$.

Secondly, calculate the prospect value and relative probability weight of each emergency response plan under the different criteria in Eqs. (31),(32) and (35). Hereafter, based on Eq. (38) the prospect value matrices of d_1, d_2 and d_3 can be attained as follows.

$$V_{(1)} = \begin{pmatrix} 0.0486 & -0.1531 & 0.0090 & 0.1745 & 0.0382 & 0.0239 & -0.2137 \\ -0.0179 & -0.2598 & -0.0254 & -0.1459 & -0.0195 & 0.0673 & -0.1326 \\ -0.1091 & 0.0154 & 0.0440 & 0.0422 & 0.0020 & -0.1083 & 0.0844 \\ 0.0404 & -0.1531 & -0.1665 & 0.1745 & -0.1265 & -0.0073 & 0.0083 \\ -0.1266 & 0.0425 & -0.0046 & -0.2021 & -0.2450 & -0.0159 & 0.0767 \end{pmatrix}$$

$$V_{(2)} = \begin{pmatrix} 0.0232 & -0.0241 & -0.0140 & 0.0474 & -0.0351 & -0.0073 & -0.0426 \\ -0.0366 & -0.2393 & -0.2346 & -0.0683 & 0.0387 & -0.1083 & 0.0160 \\ -0.0242 & 0.0373 & -0.0110 & 0.0474 & 0.0067 & 0.0388 & -0.0948 \\ 0.0130 & -0.0130 & 0.0236 & 0.0267 & 0.0167 & 0.0374 & 0.0269 \\ -0.1125 & -0.6409 & -0.0389 & 0.0328 & 0.0164 & 0.0142 & -0.0824 \end{pmatrix}$$

Table 6
The value of evaluation from DMs in the state of s_1.

		c_1	c_2	c_3	c_4	c_5	c_6	c_7
DM_1	a_1	0.1136	−0.1971	0.1249	−0.1816	0.105	−0.3771	0.1859
	a_2	−0.0736	−1.4131	−0.2609	0.0057	0.105	0.0091	−0.2019
	a_3	−0.0736	0.1891	0.3249	0.2056	−0.081	0.2091	−1.2291
	a_4	0.3136	−0.1971	−0.0609	−0.1816	−0.081	−0.1771	−0.2019
	a_5	−0.2736	0.3891	−0.0609	0.2056	−0.281	0.2091	−1.2291
DM_2	a_1	−0.0736	0.1891	−0.0609	0.0057	−0.081	−0.1771	−0.0029
	a_2	−0.2736	−0.1971	−0.2609	−0.1816	0.305	0.2091	0.1859
	a_3	0.1136	0.1891	0.1249	0.0057	0.105	0.0091	−0.0029
	a_4	0.1136	−0.1971	0.1249	0.0057	−0.081	−0.1771	−0.2019
	a_5	−0.0736	−5.4275	−0.2609	0.2056	−0.081	0.0091	−0.0029
DM_3	a_1	0.1136	−1.4131	0.1249	0.0057	0.305	0.0091	0.3859
	a_2	−0.0736	0.1891	−0.0609	−0.1816	0.105	0.0091	−5.1581
	a_3	−0.2736	−1.4131	0.1249	0.0057	0.105	−0.1771	−0.2019
	a_4	0.5136	−0.3971	−0.0609	0.0057	−0.281	0.0091	0.3859
	a_5	−0.0736	−1.4131	0.1249	0.0057	−0.081	0.4091	−0.2019

$$V_{(3)} = \begin{pmatrix} 0.0545 & -0.1743 & 0.0103 & 0.4413 & 0.0389 & 0.0388 & -0.0351 \\ -0.0016 & 0.0154 & -0.0695 & 0.0408 & 0.0387 & 0.0256 & -0.0037 \\ -0.1266 & -0.2598 & 0.0418 & -0.1276 & 0.0064 & 0.0374 & 0.0680 \\ 0.0683 & -0.2131 & -0.2319 & -0.0796 & -0.1355 & -0.0176 & -0.3817 \\ -0.1828 & -0.2061 & 0.0231 & 0.5083 & -0.1317 & -0.0771 & 0.0680 \end{pmatrix}$$

Then through the standardization of Eqs. (40) and (41), the modified prospect matrices of d_1, d_2 and d_3 can be obtained.

$$V_{(1)mod} = \begin{pmatrix} 0.0000 & 0.6471 & 0.1666 & 1.0000 & 0.0000 & 0.7530 & 0.0000 \\ 0.3794 & 1.0000 & 0.3298 & 0.1493 & 0.2039 & 1.0000 & 0.2721 \\ 0.8997 & 0.0896 & 0.0000 & 0.6487 & 0.1280 & 0.0000 & 1.0000 \\ 0.0471 & 0.6471 & 1.0000 & 1.0000 & 0.5817 & 0.5752 & 0.7448 \\ 1.0000 & 0.0000 & 0.2311 & 0.0000 & 1.0000 & 0.5262 & 0.9741 \end{pmatrix}$$

$$V_{(2)mod} = \begin{pmatrix} 0.0000 & 0.0905 & 0.1456 & 1.0000 & 1.0000 & 0.6865 & 0.4286 \\ 0.4407 & 0.4079 & 1.0000 & 0.0000 & 0.0000 & 0.0000 & 0.9099 \\ 0.3491 & 0.0000 & 0.1343 & 1.0000 & 0.4345 & 1.0000 & 0.0000 \\ 0.0755 & 0.0742 & 0.0000 & 0.8215 & 0.2989 & 0.9906 & 1.0000 \\ 1.0000 & 1.0000 & 0.2424 & 0.8739 & 0.3031 & 0.8328 & 0.1019 \end{pmatrix}$$

$$V_{(3)mod} = \begin{pmatrix} 0.0550 & 0.6893 & 0.1150 & 0.8947 & 0.0000 & 1.0000 & 0.7707 \\ 0.2783 & 0.0000 & 0.4067 & 0.2649 & 0.0012 & 0.8862 & 0.8406 \\ 0.7762 & 1.0000 & 0.0000 & 0.0000 & 0.1865 & 0.9880 & 1.0000 \\ 0.0000 & 0.8304 & 1.0000 & 0.0756 & 1.0000 & 0.5130 & 0.0000 \\ 1.0000 & 0.8047 & 0.0681 & 1.0000 & 0.9780 & 0.0000 & 1.0000 \end{pmatrix}$$

Finally, the group prospect matrix is calculated by Eq. (38) given as below.

$$V = \begin{pmatrix} 0.0165 & 0.4928 & 0.1448 & 0.9684 & 0.3000 & 0.8071 & 0.3598 \\ 0.3674 & 0.5224 & 0.5539 & 0.1392 & 0.0819 & 0.6659 & 0.6340 \\ 0.6975 & 0.3358 & 0.0403 & 0.5595 & 0.2375 & 0.5964 & 0.7000 \\ 0.0415 & 0.5302 & 0.7000 & 0.6691 & 0.6224 & 0.6811 & 0.5979 \\ 1.0000 & 0.5414 & 0.1856 & 0.5622 & 0.7843 & 0.4603 & 0.7202 \end{pmatrix}$$

Step 3. ***Consensus reaching process***

For this part, we measure the distances between the individual matrices and the group matrix by Eq. (26), the results are as follows $d\left(V_{(1)mod}, V\right) = 0.0436$, $d\left(V_{(2)mod}, V\right) = 0.0620$ and $d\left(V_{(3)mod}, V\right) = 0.0529$, which can be seen that $d\left(V_{(2)mod}, V\right)$ and $d\left(V_{(3)}, V\right)$ exceed the threshold η. Hence, Eq. (28) is used to modify $V_{(2)mod}$, $V_{(3)mod}$ and V, the modified results are given below.

$$V'_{(2)mod} = \begin{pmatrix} 0.0083 & 0.2916 & 0.1452 & 0.9842 & 0.6500 & 0.7468 & 0.3942 \\ 0.4041 & 0.4651 & 0.7770 & 0.0696 & 0.0410 & 0.3329 & 0.7719 \\ 0.5233 & 0.1679 & 0.0873 & 0.7797 & 0.3360 & 0.7982 & 0.3500 \\ 0.0585 & 0.3022 & 0.3500 & 0.7453 & 0.4606 & 0.8358 & 0.7990 \\ 1.0000 & 0.7707 & 0.2140 & 0.7180 & 0.5437 & 0.6466 & 0.4111 \end{pmatrix}$$

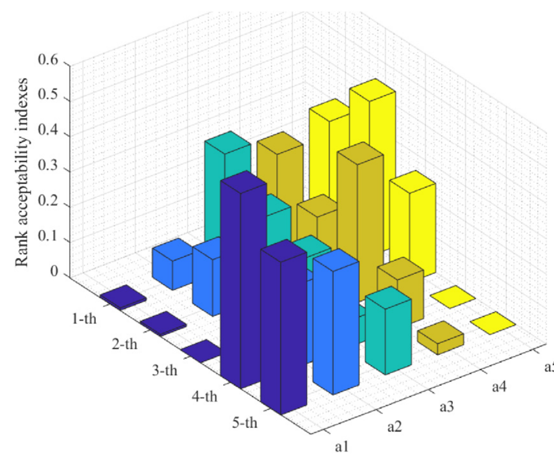

Fig. 6. The rank acceptability indexes of emergency response plans.

$$V'_{(3)mod} = \begin{pmatrix} 0.0358 & 0.5910 & 0.1299 & 0.9316 & 0.1500 & 0.9036 & 0.5653 \\ 0.3229 & 0.2612 & 0.4803 & 0.2020 & 0.0415 & 0.7760 & 0.7373 \\ 0.7368 & 0.6679 & 0.0201 & 0.2797 & 0.2120 & 0.7922 & 0.8500 \\ 0.0207 & 0.6803 & 0.8500 & 0.3723 & 0.8112 & 0.5971 & 0.2990 \\ 1.0000 & 0.6731 & 0.1269 & 0.7811 & 0.8812 & 0.2302 & 0.8601 \end{pmatrix}$$

$$V' = \begin{pmatrix} 0.0132 & 0.5236 & 0.1492 & 0.9747 & 0.2400 & 0.7963 & 0.2878 \\ 0.3698 & 0.6179 & 0.5091 & 0.1412 & 0.1063 & 0.7327 & 0.5616 \\ 0.7379 & 0.2866 & 0.0322 & 0.5773 & 0.2156 & 0.4771 & 0.7600 \\ 0.0426 & 0.5536 & 0.7600 & 0.7353 & 0.6142 & 0.6599 & 0.6273 \\ 1.0000 & 0.4331 & 0.1947 & 0.4497 & 0.8275 & 0.4735 & 0.7710 \end{pmatrix}$$

Again, we recalculate the level of similarity of the individual matrix and the group matrix, $d\left(V'_{(1)}, V\right) = 0.0349$, $d\left(V'_{(2)}, V\right) = 0.0370$ and $d\left(V'_{(3)}, V\right) = 0.0308$, all of them satisfying the condition shown in Eq. (27). Therefore, V' is the consensus group prospect matrix.

Step 4. ***SMAA-MULTIMOORA method***

Let the consensus group prospect matrix be used in the extended MULTIMOORA method, calculate the rank acceptability index in Eq. (22) and the central weight vector in Eq. (23) of each emergency response plan respectively.

Eventually, Fig. 6 exhibits the distribution of the rank acceptability indexes, it can be obtained the final ranking results of

Algorithm 1 Pseudocode for the IT2FS-PT^3 integrated with the extended MULTIMOORA method

```
Input: Criteria set C, Emergency response plan set A, States set S with time line set O, DM set D with relative weight set λ, Linguistic term set L with LMF and UMF, Linguistic decision matrix set X;
Output: The optimal emergency response plan in an acceptable consensus level
function IT2FS-PT^3(C, A, D, L, S, O, X)
    group prospect value matrix ← zeros(length(A), length(C))
    for each DM = 1 → length(D) do
        prospect value matrix ← zeros(length(A), length(C))
        for each state = 1 → length(S) and time= 1 → length(O) do
            Calculate the IT2FSs-based linguistic terms' centroids shown in Eqs. (3) and (4)) by KM algorithm
            Calculate of the dynamic reference point in Eq. (33); Consider the six possible cases in Table 1
            Construct of the value function and weight function in Eqs. (31), (32) and (35)
            Obtain the prospect value in Eq. (38)
        end for
        return prospect value matrix
    end for
    function CONSENSUS TEST(prospect value matrices,λ,threshold)
        group prospect value matrix ← Eq. (25)
        threshold ← η
        for each DM = 1 → length(D) do
            Calculate the distance between the individuals and the group in Eq. (26)
            if distance > threshold shown in Eq. (27) then
                Reconstruct the individual prospect value matrix in Eq. (28)
            end if
        end for
    end function
    return group prospect value matrix
end function

function EXTENDED MULTIMOORA(the agreeable group prospect value matrix)
    function MONTE CARLO SIMULATION
        for time=1 → 1000 do
            Generate a set of criteria weight w_j in a normal distribution
            Calculate the utility values in RS, RP, FMF method
            Aggregate the three subordinate values by BC method
        end for
    end function
    Calculate the measurements in Eqs. (22), (23)
end function
```

Table 7
Emergency response plans' rank acceptability indexes.

	1st	2nd	3rd	4th	5th
a_1	0.0070	0.0830	0.3300	0.2720	0.3080
a_2	0.0060	0.1610	0.2260	0.1680	0.4390
a_3	0.0000	0.1730	0.1830	0.3910	0.2530
a_4	0.5540	0.2330	0.0750	0.1380	0.0000
a_5	0.4330	0.3500	0.1860	0.0310	0.0000

these emergency response plans according to the rank acceptability indexes and the central weight vectors of emergency response plans from Tables 7 and 8 as: $a_4 \succ a_5 \succ a_2 \succ a_3 \succ a_1$.

Table 8
Emergency response plans' central weight vectors.

	c_1	c_2	c_3	c_4	c_5	c_6	c_7
a_1	0.0160	0.0880	0.0410	0.5170	0.0230	0.2880	0.0270
a_2	0.1130	0.0860	0.1020	0.0420	0.0430	0.5210	0.0920
a_3	NE	NE	NE	NE	NE	NE	NE
a_4	0.0640	0.1320	0.1780	0.1760	0.1330	0.1710	0.1450
a_5	0.1930	0.1250	0.0980	0.1030	0.1810	0.1340	0.1660

[1] NE denotes "Not Exist", that is, a_3 has got no possibility to rank the first place.

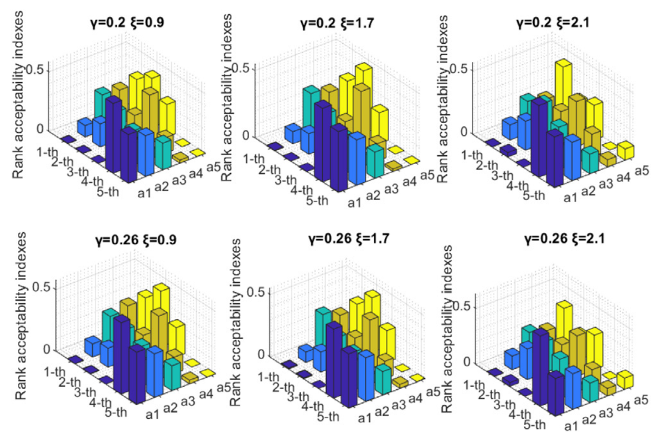

Fig. 7. The rank acceptability indexes of emergency plans with different γ and ξ.

4.3. Sensitivity analysis

In this part, we explore the influences of related parameters γ and ξ on the reference point vector and the final ranking results. From the aforementioned in Section 2, parameters γ and ξ in Eq. (8) determine the curvature and the elevation of $f(x)$ respectively, or in another perspective, γ and ξ control the importance level of the current evaluation matrices of DMs in this period.

It can be intuitively that the change of the parameter γ and ξ merely have direct impacts on the reference point $h(s_3)^{o_3}$. Table 9 exhibits the values of $h(s_3)^{o_3}$ and the ranking sequence of emergency response plans in different values of γ and ξ. And Fig. 7 displays the distribution of the rank acceptability indexes of emergency plans with different γ and ξ.

In the following discussion, we elaborate on the changes of $h(s_3)^{o_3}$ and the final ranking results from Table 9 separately, which are described as.

- For the values of $h(s_3)^{o_3}$
  When the value of γ is fixed, through increasing the value of ξ, the $h(s_3)^{o_3}$ displays a distinct upward trend. Take an example, when $\gamma = 0.2, \xi = 0.9$ the value of $h(s_3)^{o_3}(1)$ is [0.5675,0.5799], while $\gamma = 0.2, \xi = 2.1$ $h(s_3)^{o_3}(1)$ is [0.5903,0.6029]; meanwhile, if the value of ξ is constant, the value of $h(s_3)^{o_3}(1)$ has been slightly increased, and there is basically no change in the length of the intervals.
- For the final results
  It can be seen from Table 9 that parameters γ and ξ caused an unobviously change in the ranking of emergency response plans with keep the optimal alternative being a_4 and the second optimal alternative being a_5. This indicates the parameters presents less sensitive to the final ranking results in the proposed study.

Table 9
The values of $h(s_3)^{o_3}$ and ranking results of alternatives in different γ and ξ.

γ	ξ	$h(s_3)^{o_3}$	Ranking results
0.2	0.9	(0.5675, 0.5276, 0.4432, 0.6797, 0.4181, 0.5222, 0.6652)[a] (0.5799, 0.5418, 0.4569, 0.6929, 0.4317, 0.5356, 0.6777)[b]	$a_4 \succ a_5 \succ a_1 \succ a_3 \succ a_2$
	1.7	(0.5852, 0.5161, 0.4387, 0.6905, 0.4154, 0.5195, 0.6741) (0.5978, 0.5301, 0.4526, 0.7035, 0.4291, 0.5330, 0.6866)	$a_4 \succ a_5 \succ a_1 \succ a_3 \succ a_2$
	2.1	(0.5903, 0.5128, 0.4374, 0.6935, 0.4146, 0.5187, 0.6767) (0.6029, 0.5268, 0.4513, 0.7065, 0.4284, 0.5323, 0.6891)	$a_4 \succ a_5 \succ a_2 \succ a_3 \succ a_1$
0.26	0.9	(0.5681, 0.5272, 0.4431, 0.6801, 0.4180, 0.5221, 0.6655) (0.5805, 0.5414, 0.4568, 0.6933, 0.4316, 0.5355, 0.6781)	$a_4 \succ a_5 \succ a_1 \succ a_3 \succ a_2$
	1.7	(0.5858, 0.5157, 0.4385, 0.6908, 0.4153, 0.5194, 0.6744) (0.5983, 0.5298, 0.4524, 0.7038, 0.4290, 0.5329, 0.6869)	$a_4 \succ a_5 \succ a_2 \succ a_3 \succ a_1$
	2.1	(0.5908, 0.5125, 0.4373, 0.6938, 0.4145, 0.5186, 0.6769) (0.6034, 0.5265, 0.4512, 0.7068, 0.4283, 0.5322, 0.6894)	$a_4 \succ a_5 \succ a_2 \succ a_3 \succ a_1$

[a]The lower bound of $h(s_3)^{o_3}$ when $\gamma = 0.2, \xi = 0.9$.
[b]The upper bound of $h(s_3)^{o_3}$ when $\gamma = 0.2, \xi = 0.9$.

Table 10
Ranking results of emergency response plans in different methods.

	Main Methods	Ranking Indices	Ranking Results
Wang et al.'s [42] Method	Group emergency decision making method based on PT	$v(a_1) = 0.4320$, $v(a_2) = 0.5321$, $v(a_3) = 0.4194$, $v(a_4) = 0.5623$, $v(a_5) = 0.5586$	$a_4 \succ a_5 \succ a_2 \succ a_1 \succ a_3$
Wang et al.'s [57] Method	MLUTIMOORA method in IT2FSs environment	$s^*_{rs}(a_1) > s^*_{rs}(a_3) > s^*_{rs}(a_2) > s^*_{rs}(a_4) > s^*_{rs}(a_5)$ $s^*_{IT2p}(a_1) < s^*_{IT2p}(a_2) < s^*_{IT2p}(a_4) < s^*_{IT2p}(a_3) < s^*_{IT2p}(a_5)$ $s^*_{fm}(a_1) > s^*_{fm}(a_3) > s^*_{fm}(a_2) > s^*_{fm}(a_4) > s^*_{fm}(a_5)$	$a_1 \succ a_3 \succ a_2 \succ a_4 \succ a_5$
The Proposed Method	PT^3 and with the extended MULTIMOORA method in IT2FSs environment	The indexes shown in Tables 7 and 8	$a_4 \succ a_5 \succ a_1 \succ a_3 \succ a_2$

Table 11
The linguistic evaluation information of DMs in the state of s_2.

		c_1	c_2	c_3	c_4	c_5	c_6	c_7
DM_1	a_1	UI	SI	VUI	I	UI	I	SI
	a_2	SI	I	SI	I	SI	VI	I
	a_3	UI	SI	UI	UI	SI	VUI	VI
	a_4	VUI	SI	I	I	VI	SI	I
	a_5	VI	UI	UI	SI	I	SI	I
DM_2	a_1	SI	SI	I	VI	UI	SI	SI
	a_2	I	VI	VI	I	UI	VUI	I
	a_3	UI	SI	SI	VI	SI	I	I
	a_4	I	SI	SI	I	UI	SI	VI
	a_5	VI	I	UI	I	UI	I	SI
DM_3	a_1	UI	SI	UI	SI	VUI	I	VI
	a_2	I	SI	SI	I	VUI	SI	SI
	a_3	VI	I	VUI	SI	SI	SI	I
	a_4	UI	I	I	I	UI	I	VUI
	a_5	VI	UI	SI	VI	SI	UI	I

4.4. Comparative analysis

In what follows, we conduct the comparative analysis with the exisited MCDM methods [42,57] in emergency situation to verify the feasibility and comprehensiveness of this study. The corresponding calculations and analysis are all based on the same scenario mentioned above.

Firstly, Wang et al. [42] considered and emphasized the psychological behaviors of DMs in risk and uncertainty environment for solving group emergency decision making problem. Therefore, they applied PT into decision making process, simultaneously, the judgments provided by DMs were expressed in the interval-based linguistic terms. Then Wang et al. [57] discussed the MULTIMOORA method under IT2FS fuzzy environment. They used the IT2FSs-based linguistic terms to deal with the uncertainty and fuzzy evaluations which is the same as the proposed model, after that they calculated the ranking results by MULTIMOORA method. Table 10 represents the ranking results in different methods, it can be clearly seen that the results obtained by this proposed model are closely to the method in [42], while are different from those obtained by method in [57].

The above two studies have both considered the issue of setting criteria weights and proposed the distance based methods for determining the criteria weights. And for the GDM scenario, both of them merely used AWA operators to aggregate the individual's assessments, and the group consensus reaching process is not reflected. Compared with these methods, the features of the proposed model can be summarized in the following aspects.

- Compared with Wang et al.'s [42] method, this study introduces PT^3 and develops the dynamic reference points associated with time series, which is more flexible than PT and has wider application in dealing with emergency events. Meanwhile, this proposed model selects the IT2FSs-based linguistic terms set which is more reasonable for solving emergency response plans evaluation problems than interval-based linguistic terms.
- Compared to Wang et al.'s [57] research, this paper considers the bounded rationality of DMs, and combines PT^3 and the SMAA-MULTIMOORA method to calculate the results in a multi perspective. The introduction of SMAA method allows the stochastic input data of MULTIMOORA framework, which can increase the consistency of the final ranking results.
- In addition, in GDM process, this paper considers the group consensus and designs a consensus iterative algorithm to promote group consensus reaching. Moreover, we use Monte Carlo simulation to produce the criteria's weights randomly, thereafter, the three measurements in SMAA method are applied to testify the ranking results. It increases the robustness of results compared with the establishment of the criteria weights in the previous two studies [42,57].

Therefore, through the comparative analysis, the propose method can be applied in the process of emergency response plan evaluation in a more comprehensive perspective.

Table 12
The value of evaluation from DMs in the state of s_2.

		c_1	c_2	c_3	c_4	c_5	c_6	c_7
DM$_1$	a_1	0.3188	0.0001	0.3301	0.0108	0.1102	−0.1719	0.1911
	a_2	0.1188	−0.1919	−0.0557	0.0108	−0.0758	−0.3719	−0.0006
	a_3	0.3188	0.0001	0.1301	0.4108	−0.0758	0.4143	−0.1967
	a_4	0.5188	0.0001	−0.2557	0.0108	−0.4758	0.0143	−0.0006
	a_5	−0.2684	0.1943	0.1301	0.2108	−0.2758	0.0143	−0.0006
DM$_2$	a_1	0.1188	0.0001	−0.2557	−0.1764	0.1102	0.0143	0.1911
	a_2	−0.0684	−0.3919	−0.4557	0.0108	0.1102	0.4143	−1.3568
	a_3	0.3188	0.0001	−0.0557	−0.1764	−0.0758	−0.1719	−1.3568
	a_4	−0.0684	0.0001	−0.0557	0.0108	0.1102	0.0143	−0.1967
	a_5	−0.2684	−0.1919	0.1301	0.0108	0.1102	−0.1719	0.1911
DM$_3$	a_1	0.3188	0.0001	0.1301	0.2108	0.3102	−0.1719	−0.1967
	a_2	−0.0684	0.0001	−0.0557	0.0108	0.3102	0.0143	0.1911
	a_3	−0.2684	−0.1919	0.3301	0.2108	−0.0758	0.0143	−1.2965
	a_4	0.3188	−0.1919	−0.2557	0.0108	0.1102	−0.1719	0.5911
	a_5	−0.2684	0.1943	−0.0557	−0.1764	−0.0758	0.2143	−1.2965

Table 13
The linguistic evaluation information of DMs in the state of s_3.

		c_1	c_2	c_3	c_4	c_5	c_6	c_7
DM$_1$	a_1	VUI	VI	SI	I	VUI	SI	UI
	a_2	I	I	UI	UI	SI	VI	UI
	a_3	VI	SI	UI	I	UI	VUI	VI
	a_4	SI	VI	I	I	SI	UI	I
	a_5	I	VUI	SI	UI	VI	SI	VI
DM$_2$	a_1	UI	I	UI	VI	SI	UI	I
	a_2	SI	VI	I	SI	VUI	VUI	I
	a_3	I	VUI	SI	VI	VUI	VI	UI
	a_4	SI	SI	UI	VI	VUI	I	I
	a_5	I	I	SI	I	UI	SI	SI
DM$_3$	a_1	UI	SI	SI	I	UI	VI	I
	a_2	SI	SI	I	VI	VUI	I	UI
	a_3	I	I	VUI	SI	UI	I	VI
	a_4	VUI	VI	VI	SI	I	UI	VUI
	a_5	VI	I	UI	I	I	UI	VI

5. Further discussion

In this proposed model, we have proposed an integrated MCGDM method, which takes the IT2FSs, PT^3 and MULTIMOORA method into consideration. The major parts of this research are as follows: firstly, individual DMs make judgments on the emergency response plans in PT^3, then through the consensus iterative algorithm, obtain the group evaluation information. Thereafter, with the application of the extended MULTIMOORA method to calculate the final ranking results.

Generally, in the assessments of emergency response plans, linguistic terms are usually applied to express the preferences of DMs. It is difficult to obtain sufficient information in emergency events, so we use IT2FSs to quantify the expressions of terms and reduce the loss in the data processing. We consider the characteristics of DMs and introduced the PT^3. In the extended MULTIMOORA framework, the BC method is arranged to aggregate the utility values of the three subordinate methods instead of the original dominance theory, and we apply the SMAA method to randomize the criteria weight to increase the robustness of the final results.

After that, as shown in Table 9, by modifying the relevant parameters for sensitivity analysis, it can be seen that the changes of the parameters have a little effects on the final evaluation results, which illustrates the robustness of this model. Furthermore, through the comparative analysis, it can reflect the reliability of the method from the side. Based on the above discussions, the major novelty and advantages of the proposed model can be highlighted as follows.

- The proposed model uses the IT2FSs as the quantitative tool for linguistic terms for DMs making evaluations. Meanwhile the six possible cases of dealing with the centroid intervals of IT2FSs are designed, which can make the final qualified evaluation values are closer to the real DMs' assessments.
- PT^3 is applied to construct the decision making matrix of DMs, considering the bounded rationality in handling with emergency events of DMs. Furthermore, the setting of dynamic reference points corresponds to the timeliness of the development of emergency events as well.
- In the GDM situation, the distance formula in Eq. (26) is designed to examine the group consensus, and we put forward the related iterative algorithm to help consensus reaching, which is not considered in [42,57].
- The extended MULTIMOORA method is presented. Specifically, the BC method is applied to fuse the utility values of the three sub functions in MULTIMOORA framework, then the Monte Carlo simulation is constructed to randomize the criteria weights, and the corresponding indexes in the SMAA method are supposed to verify the final rankings, which increase robustness of results and make the model more suitable to deal with real cases.

6. Conclusions, limitations, and future studies

In the recent years, owing to the harmfulness caused by emergency events, researches on emergency response plans evaluation has attracted many scholars. The related studies can be seen in Refs. [58–61]. In this paper, we have developed an emergency response plans assessment method in a comprehensive way, owing to the complexity of emergency events and the bounded rationality of DMs, this proposed model combines PT^3 and the extended MULTIMOORA method with considering the group consensus reaching, the whole process is described as follows: DMs use the given linguistic terms set to make judgments on the emergency response plans, then based on centroids of IT2FSs, each term can be qualified into interval numbers, formalize the interval-based evaluation matrices. When comparing with the related reference point vectors, six possible cases are presented to measure DMs' expectation of gains or losses of alternatives. It is worth noting that we provide a formula for the formation of dynamic reference point vectors over time. Thereafter, we calculate the prospect matrix of each DM. Afterwards, through the consensus conditions, we substitute the agreeable group prospect decision matrix into the extended MULTIMOORA method, through 1000 times of Monte Carlo simulation, the related indexes in SMAA are calculated to determine the final ranking results of these emergency response plans. Finally, the emergency response plans evaluation case of COVID-19 happened in Wuhan, China further

Table 14
The value of evaluation from DMs in the state of s_3.

		c_1	c_2	c_3	c_4	c_5	c_6	c_7
DM_1	a_1	0.4858	−0.3702	−0.0476	−1.3037	0.3153	0.0194	0.3744
	a_2	−0.1017	−0.1702	0.1385	0.3908	−0.071	−0.3671	0.3744
	a_3	−0.3017	0.0157	0.1385	−1.3037	0.1153	0.4194	−0.2131
	a_4	0.0858	−0.3702	−0.2476	−1.3037	−0.071	0.2194	−0.0131
	a_5	−0.1017	0.4157	−0.0476	0.3908	−0.471	0.0194	−0.2131
DM_2	a_1	0.2858	−0.1702	0.1385	−0.1962	−0.071	0.2194	−0.0131
	a_2	0.0858	−0.3702	−0.2476	0.1908	0.3153	0.4194	−0.0131
	a_3	−0.1017	0.4157	−0.0476	−0.1962	0.3153	−0.3671	0.3744
	a_4	0.0858	0.0157	0.1385	−0.1962	0.3153	−0.1671	−0.0131
	a_5	−0.1017	−0.1702	−0.0476	−1.3037	0.1153	0.0194	0.1744
DM_3	a_1	0.2858	0.0157	−0.0476	−12.168	0.1153	−0.3671	−0.0131
	a_2	0.0858	0.0157	−0.2476	−0.1962	0.3153	−0.1671	0.3744
	a_3	−0.1017	−0.1702	0.3385	0.1908	0.1153	−0.1671	−0.2131
	a_4	0.4858	−0.3702	−0.4476	0.1908	−0.271	0.2194	0.5744
	a_5	−0.3017	−0.1702	0.1385	−12.168	−0.271	0.2194	−0.2131

illustrates the application of the model in practice. The feasibility and reliability of this study are validated by sensitivity analysis and comparison analysis with other methods.

In the future, it is possible to extend the proposed model in the following directions.

- In the initial evaluation process, DMs choose the linguistic terms to express their opinions with IT2FSs served as the quantitative tool. It will be worth studying to express the evaluation information of DMs in other ways, for instance, the generalized T2FSs [62], the use of quantum mechanics in the DMs' decision making process [63], the granular computing in GDM [64].
- This proposed model considers the psychological behavior of DMs and assumes that they are all risk-aversion, while DMs may also exist risk-neutral or risk-preference emotion in dealing with emergency events. Meanwhile, there is merely one state for each time period. In some catastrophe, there may be multiple risk states in a time period.
- We integrated PT^3 with the extended MULTIMOORA method in this paper, The introduction of the SMAA method increases the uncertainty of the input data, thereby enhancing the robustness of the results. It deserves to take further research in stochastic dominance issues [65] and generalized almost stochastic dominance issues [66].

CRediT authorship contribution statement

Jindong Qin: Conceptualization, Methodology and model design, Writing – original draft, Writing – review & editing, Funding acquisition, Supervision. **Xiaoyu Ma:** Conceptualization, Methodology, Data Curation, Writing – original draft.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

To better explain the six cases in Table 1, and make judgment for the losses or gains under different types of criteria, the main process is given as follows.

For case 1 : $x_{ij}^l < x_{ij}^r < h_j^l < h_j^r$, the relationship can be visually seen from Fig. 8.

It can be seen that $h_j = [h_j^l, h_j^r]$ completely exceeds $x_{ij} = [x_{ij}^l, x_{ij}^r]$, which indicates $x_{ij} \prec h_j$, $\Delta x_{ij} > 0$, for the cost criteria there are weak gains to DMs, while for the benefit there are strict losses to DMs. Let x'_{ij} be a random variable in interval $[x_{ij}^l, x_{ij}^r]$ satisfied a uniform distribution, the form of probability density function $f\left(x'_{ij}\right)$ is referred in Eq. (30). Thereafter, Δx_{ij} can be obtained as.

$$\begin{aligned}\Delta x_{ij} = h_j^l - x'_{ij} &= h_j^l - x_{ij}^r + \int_{x_{ij}^l}^{x_{ij}^r} \left(x_{ij}^r - x'_{ij}\right) f\left(x'_{ij}\right) d\left(x'_{ij}\right)\\ &= h_j^l - x_{ij}^r + \int_{x_{ij}^l}^{x_{ij}^r} \left(x_{ij}^r - x'_{ij}\right) \frac{1}{x_{ij}^r - x_{ij}^l} d\left(x'_{ij}\right)\\ &= h_j^l - x_{ij}^r + \frac{1}{x_{ij}^r - x_{ij}^l} \int_{x_{ij}^l}^{x_{ij}^r} \left(x_{ij}^r - x'_{ij}\right) d\left(x'_{ij}\right)\\ &= h_j^l - x_{ij}^r + \frac{1}{x_{ij}^r - x_{ij}^l} \left(x_{ij}^r x'_{ij} - \frac{1}{2}\left(x'_{ij}\right)^2\right)\Bigg|_{x_{ij}^l}^{x_{ij}^r}\\ &= h_j^l - x_{ij}^r + \frac{1}{2\left(x_{ij}^r - x_{ij}^l\right)} \cdot \left(x_{ij}^r - x_{ij}^l\right)^2\\ &= h_j^l - \frac{1}{2}\left(x_{ij}^r + x_{ij}^l\right)\end{aligned}$$

For case 2 : $x_{ij}^l < h_j^l < x_{ij}^r < h_j^r$, which is portrayed Fig. 9. In this situation, there are overlapping parts in intervals x_{ij} and h_j, the value of the overlapping part is equal to 0, which means there is neither loss nor gain for DMs, $\Delta x > 0$, the same conclusion as in **case 1**. And Δx in **case 2** presented as.

$$\begin{aligned}\Delta x_{ij} = h_j^l - x'_{ij} &= \int_{x_{ij}^l}^{h_j^l} \left(h_j^l - x'_{ij}\right) f\left(x'_{ij}\right) d\left(x'_{ij}\right)\\ &= \frac{1}{x_{ij}^r - x_{ij}^l} \int_{x_{ij}^l}^{h_j^l} \left(h_j^l - x'_{ij}\right) d\left(x'_{ij}\right)\\ &= \frac{1}{x_{ij}^r - x_{ij}^l} \left(h_j^l x'_{ij} - \frac{1}{2}\left(x'_{ij}\right)^2\right)\Bigg|_{x_{ij}^l}^{h_j^l}\\ &= \frac{\left(h_j^l - x_{ij}^l\right)^2}{2\left(x_{ij}^r - x_{ij}^l\right)}\end{aligned}$$

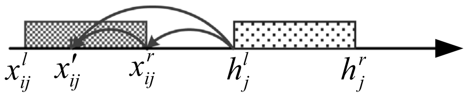

Fig. 8. The situations of interval.

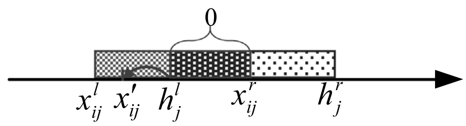

Fig. 9. The situations of interval.

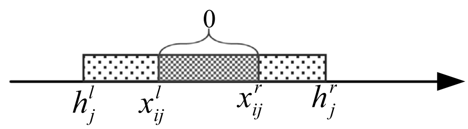

Fig. 10. The situations of interval.

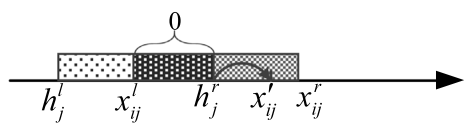

Fig. 11. The situations of interval.

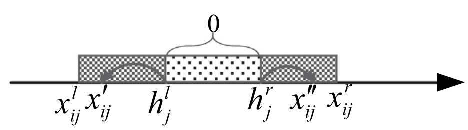

Fig. 12. The situations of interval.

For case 3 : $h_j^l < x_{ij}^l < x_{ij}^r < h_j^r$, see in Fig. 10. Interval h_j contains interval x_{ij}, it can be expressed as $[x_{ij}^l, x_{ij}^r] \subseteq \left[h_j^l, h_j^r\right]$, in this case, $\Delta x_{ij} = 0$ which means no gains or losses for DMs.

For case 4 : $h_j^l < x_{ij}^l < h_j^r < x_{ij}^r$, presented in Fig. 11. Compare with **case 4** there is an overlapping part as well, the difference is, $\Delta x < 0$, which denotes that DMs feel weak gains under the benefit criteria evaluation, strict losses under the cost criteria evaluation. The main construction of Δx is shown as follows.

$$\begin{aligned}\Delta x_{ij} = h_j^r - x'_{ij} &= \int_{h_j^r}^{x_{ij}^r} (h_j^r - x'_{ij}) f\left(x'_{ij}\right) d\left(x'_{ij}\right)\\ &= \frac{1}{x_{ij}^r - x_{ij}^l}\int_{h_j^r}^{x_{ij}^r} (h_j^r - x'_{ij}) d\left(x'_{ij}\right)\\ &= \frac{1}{x_{ij}^r - x_{ij}^l}\left(h_j^r x'_{ij} - \frac{1}{2}\left(x'_{ij}\right)^2\right)\Bigg|_{h_j^r}^{x_{ij}^r}\\ &= \frac{-\left(h_j^r - x_{ij}^r\right)^2}{2\left(x_{ij}^r - x_{ij}^l\right)}\end{aligned}$$

For case 5 : $x_{ij}^l < h_j^l < h_j^r < x_{ij}^r$, see in Fig. 12. This time, interval x_{ij} contains interval h_j, let x'_{ij}, x''_{ij} be uniformly distributed values on the interval x_{ij} which satisfy $x'_{ij} \in \left[x_{ij}^l, h_j^l\right]$ and $x''_{ij} \in \left[h_j^r, x_{ij}^r\right]$. Divide Δx_{ij} into two parts $\Delta x'_{ij}$ and $\Delta x''_{ij}$, $\Delta x_{ij} = \Delta x'_{ij} + \Delta x''_{ij}$ the solving steps are as follows.

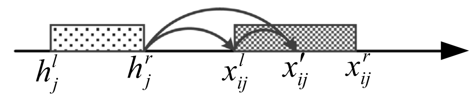

Fig. 13. The situations of interval.

Table 15
Distribution of COVID-19 states in Wuhan on March 5th.

High risk area	Medium risk area	Low risk area
Qingshan Hannan Jiangan Hanyang Qiaokou Jianghan Wuchang Hongshan Xinzhou Huangpi Jiangxia Caidian Dongxihu	0	0

$$\begin{aligned}\Delta x'_{ij} &= \int_{x_{ij}^l}^{h_j^l} \left(h_j^l - x'_{ij}\right) f\left(x'_{ij}\right) d\left(x'_{ij}\right)\\ &= \frac{1}{x_{ij}^r - x_{ij}^l}\int_{x_{ij}^l}^{h_j^l}\left(h_j^l - x'_{ij}\right) d\left(x'_{ij}\right)\\ &= \frac{1}{h_j^l - x_{ij}^l}\left(h_j^l x'_{ij} - \frac{1}{2}\left(x'_{ij}\right)^2\right)\Bigg|_{x_{ij}^l}^{h_j^l}\\ &= \frac{\left(h_j^l - x_{ij}^l\right)}{2}\end{aligned}$$

$$\begin{aligned}\Delta x''_{ij} &= \int_{h_j^r}^{x_{ij}^r} \left(h_j^r - x'_{ij}\right) f\left(x'_{ij}\right) d\left(x'_{ij}\right)\\ &= \frac{1}{x_{ij}^r - h_j^r}\int_{h_j^r}^{x_{ij}^r}\left(h_j^r - x'_{ij}\right) d\left(x'_{ij}\right)\\ &= \frac{1}{x_{ij}^r - h_j^r}\left(h_j^r x'_{ij} - \frac{1}{2}\left(x'_{ij}\right)^2\right)\Bigg|_{h_j^r}^{x_{ij}^r}\\ &= -\frac{1}{2\left(x_{ij}^r - h_j^r\right)}\cdot\left(x_{ij}^r - h_j^r\right)^2\\ &= -\frac{\left(x_{ij}^r - h_j^r\right)}{2}\end{aligned}$$

For case 6 : $h_j^l < h_j^r < x_{ij}^l < x_{ij}^r$, see in Fig. 13, It can be seen that $x_{ij} = [x_{ij}^l, x_{ij}^r]$ completely exceeds $h_j = [h_j^l, h_j^r]$, which indicates $h_j \prec x_{ij}$, $\Delta x_{ij} < 0$, the situation of **case 6** is the opposite of **case 1**, Δx_{ij} is presented as (see Tables 11–18).

$$\begin{aligned}\Delta x_{ij} = h_j^r - x'_{ij} = h_j^r - x_{ij}^l &+ \int_{x_{ij}^l}^{x_{ij}^r}(x_{ij}^l - x'_{ij}) f\left(x'_{ij}\right) d\left(x'_{ij}\right)\\ &= h_j^r - x_{ij}^l + \frac{1}{x_{ij}^r - x_{ij}^l}\int_{x_{ij}^l}^{x_{ij}^r}\left(x_{ij}^l - x'_{ij}\right) d\left(x'_{ij}\right)\\ &= h_j^r - x_{ij}^l + \frac{1}{x_{ij}^r - x_{ij}^l}\left(x_{ij}^l x'_{ij} - \frac{1}{2}\left(x'_{ij}\right)^2\right)\Bigg|_{x_{ij}^l}^{x_{ij}^r}\end{aligned}$$

Table 16
Distribution of COVID-19 states in Wuhan on March 24th.

High risk area	Medium risk area	Low risk area
0	Qingshan Hannan Jiangan Hanyang Qiaokou Jianghan Wuchang Hongshan	Xinzhou Huangpi Jiangxia Caidian Dongxihu

Table 17
Distribution of COVID-19 states in Wuhan on April 7th.

High risk area	Medium risk area	Low risk area
0	Qiaokou	Qingshan Hannan Jiangan Hanyang Jianghan Wuchang Hongshan Xinzhou Huangpi Jiangxia Caidian Dongxihu

Table 18
Distribution of COVID-19 states in Wuhan on April 28th.

High risk area	Medium risk area	Low risk area
0	0	Qingshan Hannan Jiangan Hanyang Qiaokou Jianghan Wuchang Hongshan Xinzhou Huangpi Jiangxia Caidian Dongxihu

$$= h_j^r - x_{ij}^l - \frac{1}{2\left(x_{ij}^r - x_{ij}^l\right)} \cdot \left(x_{ij}^r - x_{ij}^l\right)^2$$
$$= h_j^r - \frac{1}{2}\left(x_{ij}^r + x_{ij}^l\right)$$

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