

Research Article

Hybrid TODIM Method with Crisp Number and Probability Linguistic Term Set for Urban Epidemic Situation Evaluation

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Emergency medical services during the COVID-19 epidemic have become the focus of worldwide attention, and how to effectively respond to urban epidemic situation during a complex environment has become a global challenge. Emergency decision-making can be considered as a multicriteria decision-making (MCDM) problem, which involves multiple criteria or attributes about qualitative and quantitative aspects. So, in this paper, based on the TODIM method, a hybrid TODIM method with crisp number and probability linguistic term set is first provided to evaluate the severity of urban COVID-19 epidemic situation during a complex humanitarian crisis environment. In this hybrid method, the quantitative aspects are evaluated on the basis of precise numerical values, and the qualitative aspects are evaluated by means of probability linguistic term set, which can not only express their judgments or linguistic preference with multiple linguistic terms but also reflect different importance degrees or probability degrees of all the possible linguistic information or preference information. In addition, the concept of entropy and probability linguistic entropy is applied to induce hybrid criteria weight information. Furthermore, sensitivity analysis of the parameter about attenuation factor of the losses in the hybrid TODIM method, which considers the psychology factors and cognitive behavior of the DMs, is further conducted on a case study, to verify the effectiveness and stability of the proposed method for urban epidemic situation evaluation according to the results of this study.

1. Introduction

The frequent occurrence of emergency medical incidents has caused a great deal of property losses and a lot of casualties [1]. Until April 5, 2020, the global COVID-19 epidemic has gotten further intensified as the global death toll due to this deadly virus soars to 64,701, and the total confirmed cases surge to 1,201,591 around the world according to the statistical data provided by Johns Hopkins University. The highest number of confirmed cases in the world is in the United States, with a cumulative total of more than 310,000 cases, and the highest number of deaths is in Italy, with a cumulative total of 15,362 cases. Emergency medical services during the COVID-19 epidemic have become the focus of worldwide attention, and the response to the COVID-19 outbreak has become a global challenging issue.

Emergency medical management and epidemic situation evaluation have a complex evolutionary process, and emergency decision-making is very difficult to deal with the traditional decision theory. The decision-making on epidemic situation evaluation of accidental medical emergencies usually concerns about multiple criteria or attributes about qualitative and quantitative aspects, a finite number of alternatives, semantic benefits, and interests of multiple stakeholders, and it can be considered as a complex multicriteria decision-making (MCDM) problem. Kahneman and Tversky [2] pointed out that the decision-makers (DMs) play a limited rational role in the complex decision-making process; in other words, the psychology and behavior of DMs may be the important factors which can affect the decision-making results. The TODIM method, first proposed by Gomes and Lima [3], is an interactive MCDM method considering the psychology factors and cognitive behavior of the DMs [4]. Liu and Teng [5] proposed

an extended TODIM method based on intuitionistic uncertain linguistic variables for multiple attribute group decision-making. Rani et al. [6] proposed an extended intuitionistic fuzzy TODIM technique for multicriteria decision-making method based on Shapley weighted divergence measure. Davoudabadi et al. [7] proposed a new last aggregation method of multiattribute group decision-making based on concepts of TODIM, WASPAS, and TOPSIS under interval-valued intuitionistic fuzzy uncertainty. Although this TODIM method has done a lot of outreach and extension, it is still not well studied and applied for epidemic situation evaluation in the emergency medical decision-making process.

The DMs usually need data and information to make effective decisions, especially for complex decisions. In general, emergency decision-making on the COVID-19 outbreak is considered as a multicriteria decision-making (MCDM) problem, which involves multiple criteria or attributes about qualitative and quantitative aspects. The quantitative aspects are evaluated on the basis of precise numerical values, and the qualitative aspects are evaluated by means of uncertainty including vagueness and ambiguity [8], such as fuzzy set theory, rough set theory, and neutrosophic set theory. However, vague data are uncertain because they lack detail or precision, and ambiguous data are uncertain because they are subject to multiple interpretations [9]. Probability linguistic term set (PLTS) is provided by Pang et al. [10] as a new type of linguistic variable, which can not only express their judgments or linguistic preference with multiple linguistic terms but also reflect different importance degrees or probability of all the possible linguistic information or preference information. Liu and You [4] extended the TODIM with PLTS to solve the multiattribute decision-making problems by an example of corporate project evaluation, and the objective weights are determined based on the traditional measure of information entropy under probabilistic linguistic environment. In this paper, firstly, the extended hybrid TODIM method with crisp number and PLTS is first provided to evaluate the severity of urban COVID-19 epidemic situation. Secondly, the objective weights for PLTS are induced and determined based on the concept of probability linguistic entropy, which has the advantages of simple calculation and clear concept.

In emergency medical management, decision-making process has become more and more complex because many of the attributes are difficult to quantify [11–13] and decisions are usually made with subjective preference information in human perceptual timeframes under pressure, lack of knowledge, and data cases [14, 15]. Furthermore, their effectiveness can be constrained due to the complexity of the decision-making process and the intricacy of systems [13, 16]. How to effectively respond to the accidental medical emergencies and evaluate the severity of urban COVID-19 epidemic situation during a complex environment has become a global challenge.

To sum up, this paper focuses on the development of a hybrid TODIM method with crisp number and probability linguistic term set, based on the TODIM method which can consider the psychology factors and cognitive behavior of the DMs, for aiming to assist DMs to evaluate the severity of urban COVID-19 epidemic situation involved in emergency

medical management. Five main works of this paper that have led to its novelty are as follows: (1) A hybrid TODIM method with crisp number and probability linguistic term set is first provided to evaluate the severity of urban COVID-19 epidemic situation during a complex humanitarian crisis environment. (2) The proposed hybrid TODIM method involves multiple criteria or attributes about qualitative and quantitative aspects, considering the complexity of emergency decision-making process. (3) The proposed hybrid TODIM method can not only express their judgments or linguistic preference with multiple linguistic terms, but also reflect different importance degrees or probability degrees of all the possible linguistic information or preference information. (4) The concept of entropy and probability linguistic entropy is applied to induce hybrid criteria weight information, which has the advantages of simple calculation and clear concept. (5) Sensitivity analysis of the parameter in the hybrid TODIM method, which considers the psychology factors and cognitive behavior of the DMs, is further carried out to demonstrate the effectiveness and stability of the proposed hybrid method for urban epidemic situation evaluation.

The rest of this paper is organized as follows. Section 2 reviews the related research. Section 3 introduces some brief backgrounds required for this paper. In Section 4, a hybrid TODIM method with crisp number and PLTS is proposed. In Section 5, an empirical study on urban COVID-19 epidemic situation evaluation during a complex humanitarian crisis environment is conducted to verify our provided method. Finally, Section 6 concludes the paper.

2. Related Works

The frequent occurrence of emergency medical incidents has caused a great deal of property losses and a lot of casualties [17]. In the meantime, it has also promoted the theoretical research and technology development to deal with emergency problems. Pullum and Ramanathan [18] indicated that data-driven machine learning tools should be developed to automate discovery for helping DMs gain quantifiable insights on emerging disease. Wang et al. [19] identified EMS emergency responses with attempted advanced airway management. Temple et al. [20] employed the GRADE method to conduct a systematic literature review and search multiple databases to examine the effects of caffeine on results of interest. Lazzara et al. [21] synthesized the literature pertinent to multiteam systems and emergency medical services to assist the prehospital community in strengthening patient care. However, epidemic situation evaluation has a complex evolutionary process. The emergency decision-making on epidemic situation evaluation usually concerns about multiple criteria or attributes about qualitative and quantitative aspects, a finite number of alternatives, semantic benefits, and interests of multiple stakeholders, which is essentially considered as a complex multicriteria decision-making (MCDM) problem. Based on the complexity of the emergency decision-making process, the TODIM method is still not well studied and applied for epidemic situation evaluation in the emergency medical decision-making, although it has done a lot of outreach and extension.

MCDM has made remarkable progress and has evolved into a mature discipline, which concerns about multiple conflicting criteria, a finite number of alternatives, and multiple opinions of DMs [1, 22–24]. Kahneman and Tversky [2] pointed out that the DMs play a limited rational role in the complex decision-making process; in other words, the psychology and behavior of DMs may be the important factors which affect the decision-making results. TODIM method, an interactive MCDM method, is proposed by Gomes and Lima [3], which can consider the psychology factors and cognitive behavior of the DMs [4] to address decision-making problems [10, 25–27].

Decisions usually need data information, particularly for complex decisions, which involve multiple criteria about qualitative and quantitative aspects. The quantitative aspects are usually evaluated on the base of accurate numerical values, and the qualitative aspects are usually evaluated by means of uncertainty including vagueness and ambiguity [8]. However, vague data are uncertain because they lack detail or precision, and ambiguous data are uncertain because they are subject to multiple interpretations [9]. It is impossible to deal with this imprecise situation with the traditional MCDM method. PLTS is provided by Pang et al. [10] as a new type of linguistic variable for indicating fuzzy data information, which can express and reflect different importance degrees or probability of all the possible linguistic information with multiple linguistic terms. For instance, when one DM is evaluating the severity of the urban epidemic situation, based on self-awareness of the epidemic, the DM may think he/she is 30% sure the urban epidemic is “very serious,” 50% sure it is “serious,” and 20% sure it is “general”. It is obvious that the problem of urban epidemic situation evaluation needs to be integrated with PLTS to express complex and uncertain information. So, this paper, based on the TODIM method, provides a hybrid TODIM method with crisp number and PLTS to evaluate the severity of urban COVID-19 epidemic situation.

Besides, in the application of TODIM method, some scholars have done some research and development. Fan et al. [28] proposed an extended TODIM method to solve the hybrid MADM problem with crisp numbers, interval numbers, and fuzzy numbers. Liu and Teng [29] extended the TODIM method to 2-dimensional uncertain linguistic information for

multiple attribute group decision-making. Liu and You [4] extended the TODIM with PLTS to solve the multiattribute decision-making problems according to an example of corporate project evaluation, and during the probabilistic linguistic environment, the objective weights are determined based on the traditional measure of information entropy. Wei [26] expanded the TODIM model to the MADM with the picture fuzzy numbers. Although some achievements have been made in the application of TODIM method, the hybrid TODIM method with crisp number and PLTS has not been fully studied. Furthermore, in this paper, the extended hybrid TODIM method is first proposed to evaluate the severity of urban COVID-19 epidemic situation. In addition, Zhang et al. [27] explored the water security evaluation based on the TODIM method with probabilistic linguistic term sets, where a programming model is developed to derive the attribute weights. The attribute weights determined by mathematical programming may be separated from the characteristics of the data itself to some extent. So, in this paper, the concept of entropy and probability linguistic entropy is applied to induce hybrid criteria weight information, which has the advantages of simple calculation and clear concept.

In view of the foregoing, this paper based on the TODIM method provides a hybrid TODIM method with crisp number and PLTS to evaluate the severity of urban COVID-19 epidemic situation for aiding DMs involved in emergency medical management during a complex humanitarian crisis environment.

3. Preliminaries

In this section, some brief backgrounds of PLTS, the comparison between PLTSs, the normalization of PLTS, and the TODIM method are introduced separately.

3.1. Probabilistic Linguistic Term Set

Definition 1 (see [10]). Based on the additive linguistic term set $S = \{s_\alpha = -\tau, \dots, -1, 0, \dots, \tau\}$ [30,31], the probabilistic linguistic term set (PLTS) can be defined by Pang et al. [10] as follows:

$$L(p) = \left\{ L^{(k)}(p^k) \mid L^{(k)} \in S, p^{(k)} \geq 0, k = 1, 2, \dots, \#L(p), \sum_{k=1}^{\#L(p)} p^{(k)} \leq 1 \right\}, \quad (1)$$

where $L^{(k)}(p^{(k)})$ represents the linguistic term $L^{(k)}$ associated with the probability $p^{(k)}$ and $\#L(p)$ is the number of all different linguistic terms in $L(p)$.

If $\sum_{k=1}^{\#L(p)} p^{(k)} = 1$, then the PLTSs have complete probabilistic information of all possible linguistic terms if $\sum_{k=1}^{\#L(p)} p^{(k)} < 1$, then the PLTSs have partial probabilistic information; if $\sum_{k=1}^{\#L(p)} p^{(k)} = 0$, then the

PLTSs have completely unknown probabilistic information.

Definition 2 (see [27]). Given a probabilistic linguistic term set $L(p) = \left\{ L^{(k)}(p^k) \mid k = 1, 2, \dots, \#L(p), \sum_{k=1}^{\#L(p)} p^{(k)} \leq 1 \right\}$, on the additive linguistic term set $S = \{s_\alpha = -\tau, \dots, -1, 0, \dots, \tau\}$, the negation operation for $L(p)$ is given by

$$\text{neg}(L(p)) = \left\{ \widehat{L}^{(k)}(p^{(k)}) \mid \widehat{L}^{(k)} = \text{neg}(L^{(k)}) = \text{neg}(S_\alpha), \quad k = 1, 2, \dots, \#L(p) \right\}, \quad (2)$$

where $\text{neg}(L(p))$ is the negation operation for linguistic terms [31], defined as $\text{neg}(S_\alpha) = S_{-\alpha}$, especially, $\text{neg}(S_0) = S_0$.

3.2. The Comparison between PLTSs. First, the score of PLTS is defined and introduced by Pang et al. [10] as follows.

Definition 3 (see [32]). Let $L(p) = \{L^{(k)}(p^{(k)}) \mid k = 1, 2, \dots, \#L(p)\}$ be a PLTS and $r^{(k)}$ be the subscript of the $L^{(k)}$, then the score of $L(p)$ is given by

$$E(L(p)) = s_{\bar{\alpha}}, \quad (3)$$

$$\text{where } \bar{\alpha} = \sum_{k=1}^{\#L(p)} r^{(k)} p^{(k)} / \sum_{k=1}^{\#L(p)} p^{(k)}.$$

For any two PLTSs $L_1(p)$ and $L_2(p)$, if $E((L_1(p)) > E(L_2(p)))$, then $L_1(p)$ is superior to $L_2(p)$, denoted by $L_1(p) > L_2(p)$; if $E((L_1(p)) < E(L_2(p)))$, then $L_2(p)$ is superior to $L_1(p)$, denoted by $L_1(p) < L_2(p)$; if $E((L_1(p)) = E(L_2(p)))$, then these two PLTSs cannot be distinguished. In this case, the deviation degree of a PLTS is further defined by Pang et al. [10] as follows.

Definition 4 (see [10]). Let $L(p) = \{L^{(k)}(p^{(k)}) \mid k = 1, 2, \dots, \#L(p)\}$ be a PLTS and $r^{(k)}$ be the subscript of the $L^{(k)}$, and $E(L(p)) = s_{\bar{\alpha}}$, then the deviation degree of $L(p)$ is given by

$$\sigma(L(p)) = \sqrt{\frac{\sum_{k=1}^{\#L(p)} p^{(k)} (r^{(k)} - \bar{\alpha})^2}{\sum_{k=1}^{\#L(p)} p^{(k)}}} \quad (4)$$

For two PLTSs $L_1(p)$ and $L_2(p)$ with $E(L_1(p)) = E(L_2(p))$, if $\sigma(L_1(p)) > \sigma(L_2(p))$, then $L_1(p) < L_2(p)$; if $\sigma(L_1(p)) = \sigma(L_2(p))$, then $L_1(p)$ is indifferent to $L_2(p)$, denoted by $L_1(p) \sim L_2(p)$.

Definition 5 (see [10]). Let $L_1(p) = \{L_1^{(k)}(p^{(k)}) \mid k = 1, 2, \dots, \#L_1(p)\}$ and $L_2(p) = \{L_2^{(k)}(p^{(k)}) \mid k = 1, 2, \dots, \#L_2(p)\}$ be any two PLTSs, $\#L_1(p) = \#L_2(p)$, the distance between $L_1(p)$ and $L_2(p)$ can be defined as follows:

$$d(L_1(p), L_2(p)) = \sqrt{\frac{\sum_{k=1}^{\#L_1(p)} (p_1^{(k)} r_1^{(k)} - p_2^{(k)} r_2^{(k)})^2}{\#L_1(p)}}. \quad (5)$$

3.3. The Normalization of PLTS. The normalization of PLTSs usually has two distinct tasks. One is to estimate the ignorance degree of probabilistic information, and the other is to normalize the cardinality for computational convenience.

Definition 6 (see [10]). Given a PLTS $L(p)$ with $\sum_{k=1}^{\#L(p)} p^{(k)} < 1$, then the normalized PLTS $\tilde{L}(p)$ is defined as follows:

$$\tilde{L}(p) = \left\{ \tilde{L}^{(k)}(p^{(k)}) \mid k = 1, 2, \dots, \#L(p) \right\}, \quad (6)$$

where $\tilde{p}^{(k)} = p^{(k)} / \sum_{k=1}^{\#L(p)} p^{(k)}$, for all $k = 1, 2, \dots, \#L(p)$.

Let $L_1(p) = \{L_1^{(k)}(p_1^{(k)}) \mid k = 1, 2, \dots, \#L(p)\}$ and $L_2(p) = \{L_2^{(k)}(p_2^{(k)}) \mid k = 1, 2, \dots, \#L(p)\}$, then the normalization process can be obtained as follows:

- (1) If $\sum_{k=1}^{\#L(p)} p^{(k)} < 1$, then according to formula (6), $\tilde{L}(p)$ can be calculated.
- (2) If $\#L_1(p) \neq \#L_2(p)$, then some elements can be added to the one with the smaller number of elements. That is to say, if $\#L_1(p) > \#L_2(p)$, then the $\#L_1(p) - \#L_2(p)$ linguistic terms need to be added to $L_2(p)$, which make the numbers of all different linguistic terms in $L_1(p)$ and $L_2(p)$ equal. The added linguistic terms should be the smallest ones in $L_2(p)$, and their probabilities should be zero.

3.4. The TODIM Method. The TODIM method, proposed by Gomes and Lima [3], is an interactive MCDM method, which can capture psychology factors and cognitive behavior of DMs. On the base of prospect theory [2], the alternatives are ranked according to their overall dominance degree based on the dominance degree of each alternative over others with respect to each criterion. The steps of TODIM method can be summarized as follows [3].

Suppose there are A_i ($i = 1, 2, \dots, m$) alternatives and C_j ($j = 1, 2, \dots, n$) criteria.

Step 1: identify the decision matrix $X = (x_{ij})_{m \times n}$, where x_{ij} ($i = 1, 2, \dots, m$, $j = 1, 2, \dots, n$) is the j th criteria value with respect to the i th alternative, and x_{ij} are all crisp numbers.

Step 2: obtain the normalized decision matrix $G = (g_{ij})_{m \times n}$. The normalized decision matrix can be obtained by using the normalization method.

Step 3: calculate the relative weight w_{jr} of the criteria C_j to the reference criteria C_r as follows:

$$w_{jr} = \frac{w_j}{w_r} \quad (j = 1, 2, \dots, n), \quad (7)$$

where w_j is the weight of the criteria C_j and $w_r = \max\{w_j \mid j \in 1, 2, \dots, n\}$.

Step 4: obtain the dominance degree of alternative A_i over the alternative A_t , as follows:

$$\vartheta(A_i, A_t) = \sum_{j=1}^n \phi_j(A_i, A_t), \quad \forall (i, t). \quad (8)$$

where $\phi_j(A_i, A_t)$ is the dominance degree of the alternative A_i over the alternative A_t with respect to the criterion C_j , and it can be calculated as follows:

$$\phi_j(A_i, A_t) = \begin{cases} \sqrt{\frac{w_{jr}(g_{ij} - g_{tj})}{\sum_{j=1}^n w_{jr}}}, & \text{if } g_{ij} - g_{tj} > 0, \\ 0, & \text{if } g_{ij} - g_{tj} = 0, \\ -\frac{1}{\theta} \sqrt{\frac{\sum_{j=1}^n w_{jr}(g_{ij} - g_{tj})}{w_{jr}}}, & \text{if } g_{ij} - g_{tj} < 0, \end{cases} \quad (9)$$

where the parameter θ is the attenuation factor of the losses. There are three cases: (1) if $g_{ij} - g_{tj} > 0$, then $\phi_j(A_i, A_t)$ represents a gain; (2) if $g_{ij} - g_{tj} = 0$, then $\phi_j(A_i, A_t)$ represents a nil; and (3) if $g_{ij} - g_{tj} < 0$, then $\phi_j(A_i, A_t)$ represents a loss.

Step 5: get the overall dominance degree of the alternative A_i as follows:

$$\delta(A_i) = \frac{\sum_{t=1}^m \vartheta(A_i, A_t) - \min_i \{\sum_{t=1}^m \vartheta(A_i, A_t)\}}{\max_i \{\sum_{t=1}^m \vartheta(A_i, A_t)\} - \min_i \{\sum_{t=1}^m \vartheta(A_i, A_t)\}}. \quad (10)$$

Step 6: sort the alternatives according to the overall dominance degree $\delta(A_i)$.

The larger the value of $\delta(A_i)$ is, the better the alternative is.

4. Hybrid TODIM Method

In this section, a hybrid TODIM method with crisp number and PLTS is provided in detail.

For an MCDM problem, suppose that there are A_i ($i = 1, 2, \dots, m$) alternatives and C_j ($j = 1, 2, \dots, n$) criteria. Based on the additive linguistic term set $S = \{S_\alpha | \alpha = -\tau, \dots, -1, 0, 1, \dots, \tau\}$, the DMs assess the alternatives A_i for the criteria C_j , and the evaluation results during the probabilistic linguistic terms environment are given by $L(p) = \{L^{(k)}(p^{(k)}) | k = 1, 2, \dots, \#L(p), \sum_{k=1}^{\#L(p)} p^{(k)} \leq 1\}$.

The specific steps of the hybrid TODIM method with crisp number and PLTS are presented as follows:

Step 1: identify the decision matrix $X = (x_{ij})_{m \times n}$. The initial decision matrix can be constructed and identified with crisp number a_{ij} and PLTS $L_{ij}(p)$.

Step 2: obtain the normalized decision matrix $G = (g_{ij})_{m \times n}$. The normalized decision matrix can be obtained as follows:

(1) Crisp number: the normalization of crisp number \tilde{a}_{ij} can be obtained as follows:

$$\begin{aligned} \tilde{a}_{ij} &= \frac{a_{ij}}{\max_j a_{ij}}, & \text{for benefit criteria,} \\ \tilde{a}_{ij} &= \frac{\min_j a_{ij}}{a_{ij}}, & \text{for cost criteria.} \end{aligned} \quad (11)$$

(2) PLTS: the normalization of PLTS $L_{ij}(p)$ can be obtained as follows:

$$\widetilde{L}_{ij}(p_{ij}^{(k)}) = \begin{cases} L_{ij}(p_{ij}^{(k)}), & \text{for benefit criteria,} \\ \text{neg}(L_{ij}(p_{ij}^{(k)})), & \text{for cost criteria,} \end{cases} \quad (12)$$

where $\text{neg}(L_{ij}(p_{ij}^{(k)}))$ is the negation operation for $L_{ij}(p_{ij}^{(k)})$, which is defined in Definition 2. Besides, each criteria value of PLTS should be normalized according to Definition 6.

Step 3: calculate the entropy weight for crisp number and probability linguistic entropy weight for PLTS. There are two steps:

(1) Crisp number: the entropy weight for crisp number can be determined as follows:

(a) Obtain the entropy: according to the definition of entropy, entropy E_j of criteria C_j is determined as follows:

$$E_j = -\frac{1}{\ln m} \sum_{i=1}^m a_{ij} \ln a_{ij}. \quad (13)$$

(b) Obtain the entropy weight w'_j of criteria C_j :

$$w'_j = \frac{1 - E_j}{n - \sum_{j=1}^n E_j} \quad j = 1, 2, \dots, n. \quad (14)$$

(c) Normalize the entropy weight w_j : the entropy weight can be normalized as follows:

$$w_j = \frac{w'_j}{\sum_{j=1}^n w'_j}, \quad j = 1, 2, \dots, n. \quad (15)$$

(2) PLTS: based on the concepts of entropy, the probability linguistic entropy weight for PLTS can be obtained as follows:

(a) Based on the additive linguistic term set $S = \{S_\alpha = -\tau, \dots, -1, 0, 1, \dots, \tau\}$ [30,31], six methods for calculating the entropy value of a single linguistic term are proposed by Farhadinia [32]. One of the methods is as follows:

$$E(S_\alpha) = \sin \frac{\pi}{2} \left(\frac{\alpha + \tau}{2\tau} \right) + \sin \frac{\pi}{2} \left(\frac{-\alpha + \tau}{2\tau} \right) - 1. \quad (16)$$

(b) Let $L(p) = \{L^{(k)}(p^{(k)}) | k = 1, 2, \dots, \#L(p)\}$ be a PLTS, the probability linguistic entropy weight can be induced as follows:

$$E_{ij}(L_{ij}(p_{ij}^{(k)})) = \sum_{i=1}^{\#L(p)} p_{ij}^{(k)} [E_{ij}(S_\alpha)]. \quad (17)$$

(c) Normalize the probability linguistic entropy: the probability linguistic entropy can be normalized as follows:

$$G_{ij} = \frac{E_{ij}}{\max_{1 \leq i \leq m} \{E_{ij}\}} \quad i = 1, 2, \dots, m, j = 1, 2, \dots, n. \quad (18)$$

(d) Determine the weight: the weight of each criterion can be determined as follows:

$$w'_j = \frac{1 - \overline{G}_j}{n - \overline{G}} \quad j = 1, 2, \dots, n. \quad (19)$$

where $\overline{G}_j = \sum_{i=1}^m G_{ij}$, $\overline{G} = \sum_{i=1}^m \sum_{j=1}^n G_{ij}$.

(e) Determine the normalized weight: the normalized weight can be determined as follows:

$$w_j = \frac{w'_j}{\sum_{j=1}^n w'_j}, \quad j = 1, 2, \dots, n. \quad (20)$$

Step 4: calculate the relative weight w_{jr} of the criteria C_j to the reference criteria C_r as follows:

$$w_{jr} = \frac{w_j}{w_r} \quad (j = 1, 2, \dots, n), \quad (21)$$

where w_j is the entropy weight for crisp number, or the probability linguistic entropy weight for PLTS of the criteria C_j and $w_r = \max\{w_j \mid j \in 1, 2, \dots, n\}$.

Step 5: obtain the dominance degree ϑ of alternative A_i over the alternative A_t , as follows:

$$\vartheta(A_i, A_t) = \sum_{j=1}^n \phi_j(A_i, A_t) \quad (i, t = 1, 2, \dots, m), \quad (22)$$

where $\phi_j(A_i, A_t)$ is the dominance degree of the alternative A_i over the alternative A_t with respect to the criterion C_j , and it can be calculated as follows:

$$\phi_j(A_i, A_t) = \begin{cases} \sqrt{\frac{w_{jr} d(\widetilde{L}_{ij}(p_{ij})t - n\widetilde{L}_{ij}q(p_{tj}))}{\sum_{j=1}^n w_{jr}}}, & \text{if } \widetilde{L}_{ij}(p_{ij}) > \widetilde{L}_{ij}(p_{tj}), \\ 0, & \text{if } \widetilde{L}_{ij}(p_{ij}) \sim \widetilde{L}_{ij}(p_{tj}), \\ -\frac{1}{\theta} \sqrt{\frac{\sum_{j=1}^n w_{jr} d(\widetilde{L}_{ij}(p_{ij})t - n\widetilde{L}_{ij}q(p_{tj}))}{w_{jr}}}, & \text{if } \widetilde{L}_{ij}(p_{ij}) < \widetilde{L}_{ij}(p_{tj}), \end{cases} \quad (23)$$

where the parameter θ is the attenuation factor of the losses. There are three cases:

(1) If $\widetilde{L}_{ij}(p_{ij}) > \widetilde{L}_{ij}(p_{tj})$, then $\phi_j(A_i, A_t)$ represents a gain

(2) If $\widetilde{L}_{ij}(p_{ij}) \sim \widetilde{L}_{ij}(p_{tj})$, then $\phi_j(A_i, A_t)$ represents a nil

(3) If $\widetilde{L}_{ij}(p_{ij}) < \widetilde{L}_{ij}(p_{tj})$, then $\phi_j(A_i, A_t)$ represents a loss

In this section, the distance measure can be determined as follows:

(1) Crisp number: the distance for crisp number can be determined as follows:

$$d(a, b) = |a - b|. \quad (24)$$

(2) PLTS: the distance for PLTS can be determined according to the modified Hamming distance of PLTSs based on the normalized PLTSs proposed by Lin and Xu [33].

Step 6: get the overall dominance degree $\delta(A_i)$ of the alternative A_i as follows:

$$\delta(A_i) = \frac{\sum_{t=1}^m \vartheta(A_i, A_t) - \min_i \{\sum_{t=1}^m \vartheta(A_i, A_t)\}}{\max_i \{\sum_{t=1}^m \vartheta(A_i, A_t)\} - \min_i \{\sum_{t=1}^m \vartheta(A_i, A_t)\}}. \quad (25)$$

Step 7: sort the alternatives according to the overall dominance degree $\delta(A_i)$.

The larger the value of $\delta(A_i)$ is, the better the alternative is.

5. A Case Study

5.1. Problem Description. The outbreak of COVID-19 epidemic has spread rapidly around the world, which has caused a great deal of property losses and a lot of casualties. It is very urgent to evaluate and respond to the urban epidemic situation involved in emergency medical

management for providing scientific decision basis. Emergency medical management has a complex evolutionary process, and decision-making process has become more and more complex. In this section, a hybrid TODIM method with crisp number and PLTS is provided and presented to evaluate the severity of urban COVID-19 epidemic situation on a case study. The detailed assessment process is as follows.

Five cities A_i ($i = 1, 2, 3, 4, 5$) around the world and seven criteria C_j ($j = 1, 2, \dots, 7$) are selected to illustrate the point. These selected criteria by related literature and expert opinions are as follows: (1) C_1 : confirmed diagnosis rate per one million population; (2) C_2 : cure rate of confirmed cases; (3) C_3 : mortality rate of confirmed cases; (4) C_4 : growth rate of confirmed cases in three days; (5) C_5 : number of beds per capita of confirmed cases; (6) C_6 : people's awareness of the epidemic; and (7) C_7 : government's attitude toward the epidemic. Obviously, for evaluating the severity of urban epidemic situation, the criteria C_1 , C_3 , and C_4 are of benefit type, and C_2 , C_5 , C_6 , and C_7 are of cost type. The data information with crisp number and PLTS is presented, as shown in Table 1.

5.2. Empirical Process. Now, the detailed evaluation steps are presented as follows:

Step 1: identify the decision matrix.

The decision matrix with crisp number and PLTS is constructed and identified by the following additive linguistic term set

$$\begin{aligned} S = & \{S_{-3} = \text{extremely slight}, S_{-2} = \text{very slight}, \\ & S_{-1} = \text{slight}, S_0 = \text{general}, S_1 = \text{serious}, \\ & S_2 = \text{very serious}, S_3 = \text{extremely serious}\}, \end{aligned} \quad (26)$$

to assess the severity of urban epidemic situation as shown in Table 1, the data of crisp number originated from the data management platform, a Wechat official account. The data of PLTS come from expert opinion, and the evaluation values during the probabilistic linguistic term environment are obtained and given according to the PLTS: $L(p) = \left\{ L^{(k)}(p^k) \mid k = 1, 2, \dots, \#L(p), \sum_{k=1}^{\#L(p)} p^{(k)} \leq 1 \right\}$.

Step 2: obtain the normalized decision matrix. It is obvious that the criteria C_1 , C_3 , and C_4 are of benefit type, and C_2 , C_5 , C_6 , and C_7 are of cost type. So the normalization process is relatively simple and the normalized values can be calculated by formulas (11) and (12), Definition 2, and Definition 6, as shown in Table 2.

Step 3: calculate the relative weight. The relative weight is calculated, based on the entropy weight for crisp number and probability linguistic entropy weight for PLTS according to formulas (13)–(21), as shown in Table 3. And the criteria C_1 is the reference criteria, which has the greatest weight.

Step 4: obtain the dominance degree ϑ of the alternative A_i over the alternative A_t by formulas (22)–(24), based on the dominance degree ϕ_j of the alternative A_i over the alternative A_t with respect to the criterion C_j ($i, t = 1, 2, \dots, 5, j = 1, 2, \dots, 7$):

$$\begin{aligned} \phi_1 = & \begin{bmatrix} 0.0000 & -1.2671 & -1.5473 & -0.5776 & -0.9357 \\ 0.2753 & 0.0000 & -0.8880 & 0.2450 & 0.1856 \\ 0.3362 & 0.1929 & 0.0000 & 0.3119 & 0.2677 \\ 0.1255 & -1.1278 & -1.4354 & 0.0000 & -0.7362 \\ 0.2033 & -0.8544 & -1.2322 & 0.1599 & 0.0000 \end{bmatrix}, \\ \phi_2 = & \begin{bmatrix} 0.0000 & -0.2540 & -0.2694 & -0.2036 & -0.2814 \\ -1.7498 & 0.0000 & 0.0898 & -1.0457 & 0.1211 \\ -1.8560 & -0.6187 & 0.0000 & -1.2150 & 0.0812 \\ -1.4030 & 0.1518 & 0.1764 & 0.0000 & 0.1942 \\ -1.9385 & -0.8342 & -0.5596 & -1.3377 & 0.0000 \end{bmatrix}, \\ \phi_3 = & \begin{bmatrix} 0.0000 & 0.2283 & 0.3954 & 0.3954 & 0.2283 \\ -1.0952 & 0.0000 & 0.3228 & 0.3228 & 0.3228 \\ -1.8969 & -1.5488 & 0.0000 & 0.0000 & -1.5488 \\ -1.8969 & -1.5488 & 0.0000 & 0.0000 & -1.5488 \\ -1.0952 & 0.0000 & 0.3228 & 0.3228 & 0.0000 \end{bmatrix}, \\ \phi_4 = & \begin{bmatrix} 0.0000 & 0.2054 & 0.2179 & 0.2054 & 0.2445 \\ -2.5395 & 0.0000 & 0.0726 & 0.0000 & 0.1326 \\ -2.6936 & -0.8979 & 0.0000 & -0.8979 & 0.1110 \\ -2.5395 & 0.0000 & 0.0726 & 0.0000 & 0.1326 \\ -3.0226 & -1.6392 & -1.3715 & -1.6392 & 0.0000 \end{bmatrix}, \\ \phi_5 = & \begin{bmatrix} 0.0000 & 0.1387 & -1.2804 & -1.7891 & -1.2495 \\ -0.7903 & 0.0000 & -1.5046 & -1.9558 & -1.4785 \\ 0.2247 & 0.2640 & 0.0000 & -1.2495 & 0.0490 \\ 0.3139 & 0.3432 & 0.2193 & 0.0000 & 0.2247 \\ 0.2193 & 0.2594 & -0.2794 & -1.2804 & 0.0000 \end{bmatrix}, \\ \phi_6 = & \begin{bmatrix} 0.0000 & 0.0600 & -0.4691 & -0.3831 & -0.6635 \\ -0.7923 & 0.0000 & -0.9208 & -0.8800 & -1.0334 \\ 0.0355 & 0.0697 & 0.0000 & 0.0205 & -0.4691 \\ 0.0290 & 0.0666 & -0.2709 & 0.0000 & -0.5417 \\ 0.0502 & 0.0783 & 0.0355 & 0.0410 & 0.0000 \end{bmatrix}, \\ \phi_7 = & \begin{bmatrix} 0.0000 & -0.4785 & -0.4144 & -0.2393 & -0.3384 \\ 0.0464 & 0.0000 & 0.0232 & 0.0402 & 0.0328 \\ 0.0402 & -0.2393 & 0.0000 & 0.0328 & 0.0232 \\ 0.0232 & -0.4144 & -0.3384 & 0.0000 & -0.2393 \\ 0.0328 & -0.3384 & -0.2393 & 0.0232 & 0.0000 \end{bmatrix}, \\ \vartheta = & \begin{bmatrix} 0.0000 & -0.8592 & -2.8285 & -2.1845 & -2.4329 \\ -6.6453 & 0.0000 & -2.8049 & -3.2735 & -2.0397 \\ -5.8099 & -2.7779 & 0.0000 & -2.9972 & -1.4858 \\ -5.3477 & -2.5294 & -1.5764 & 0.0000 & -2.5145 \\ -5.5507 & -3.3285 & -3.3236 & -3.7103 & 0.0000 \end{bmatrix}. \end{aligned} \quad (27)$$

Step 5: get the overall dominance degree $\delta(A_i)$ of the alternative A_i . The overall dominance degree $\delta(A_i)$ can be obtained according to formula (25) and is listed in Table 4.

TABLE 1: Data information.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	162.2	0.05	0.04	0.46	3.2	$\{S_3(0.3), S_2(0.5), S_{-1}(0.2)\}$	$\{S_3(0.9), S_1(0.1)\}$
A_2	280.1	0.09	0.03	0.22	2.4	$\{S_3(0.5), S_2(0.4)\}$	$\{S_3(0.7), S_1(0.3)\}$
A_3	338.0	0.10	0.01	0.19	5.3	$\{S_2(0.7), S_1(0.2), S_{-2}(0.1)\}$	$\{S_3(0.8), S_1(0.1), S_0(0.1)\}$
A_4	186.7	0.07	0.01	0.22	7.3	$\{S_2(0.6), S_1(0.3), S_0(0.1)\}$	$\{S_3(0.8), S_2(0.1), S_1(0.1)\}$
A_5	226.5	0.11	0.03	0.12	5.2	$\{S_2(0.5), S_1(0.3), S_{-1}(0.2)\}$	$\{S_3(0.6), S_2(0.4)\}$

TABLE 2: Normalized data information.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
A_1	0.4799	1.0000	1.0000	1.0000	0.4384	$\{S_{-3}(0.3), S_{-2}(0.5), S_1(0.2)\}$	$\{S_{-3}(0), S_{-3}(0.9), S_{-1}(0.1)\}$
A_2	0.8287	0.5556	0.7500	0.4783	0.3288	$\{S_{-3}(0), S_{-3}(0.5556), S_{-2}(0.4444)\}$	$\{S_{-3}(0), S_{-3}(0.7), S_{-1}(0.3)\}$
A_3	1.0000	0.5000	0.2500	0.4130	0.7260	$\{S_{-2}(0.7), S_{-1}(0.2), S_2(0.1)\}$	$\{S_{-3}(0.8), S_{-1}(0.1), S_0(0.1)\}$
A_4	0.5524	0.7143	0.2500	0.4783	1.0000	$\{S_{-2}(0.6), S_{-1}(0.3), S_0(0.1)\}$	$\{S_{-3}(0.8), S_{-2}(0.1), S_{-1}(0.1)\}$
A_5	0.6701	0.4545	0.7500	0.2609	0.7123	$\{S_{-2}(0.5), S_{-1}(0.3), S_1(0.2)\}$	$\{S_{-3}(0), S_{-3}(0.6), S_{-2}(0.4)\}$

TABLE 3: The relative weight.

	C_1	C_2	C_3	C_4	C_5	C_6	C_7
Weight	0.2173	0.1452	0.2084	0.0809	0.1755	0.0757	0.0971
Relative weight	1.0000	0.6681	0.9594	0.3724	0.8077	0.3485	0.4467

TABLE 4: Overall dominance degree for all alternatives.

Alternative	The overall dominance degree	$\delta(A_i)$	Ranking
A_1	-8.3051	1.0000	1
A_2	-14.7634	0.1511	4
A_3	-13.0708	0.3736	3
A_4	-11.9680	0.5185	2
A_5	-15.9131	0.0000	5

Step 6: rank all the alternatives. The ranking of all the alternatives can be obtained according to the overall dominance degree $\delta(A_i)$ and is listed in Table 4. The larger the value of $\delta(A_i)$ is, the better the alternative is. We can see the best alternative is A_1 , and the ranking is $A_1 > A_4 > A_3 > A_2 > A_5$. That is to say, the most serious city of the urban COVID-19 epidemic is A_1 . Obviously, our proposed hybrid TODIM method is feasible and can get a good decision result because our proposed hybrid method can not only involve multiple criteria or attributes about qualitative and quantitative aspects, but also express their judgments and reflect different probability degrees of all the possible linguistic information or preference information.

5.3. Sensitivity Analysis. In order to further verify the validity and effectiveness of the hybrid TODIM method with crisp number and PLTS, sensitivity analysis of the parameter θ is carried out for urban epidemic situation evaluation. In the hybrid TODIM method, the dominance degree $\phi_j(A_i, A_t)$ of the alternative A_i over the alternative

A_t with respect to the criterion C_j is determined based on the parameter θ , which is the attenuation factor of the losses. So, it is very necessary and important to analyze the sensitivity of the parameter θ according to the different values for each simulation, and the ranking results are presented in Table 5.

From Table 5, the ranking orders of alternatives are consistent when the parameter θ takes different values from 0.1 to 2, which indicates the validity, effectiveness, and stability of the proposed hybrid TODIM method with the changes of the attenuation parameter θ . And our proposed hybrid TODIM method involves multiple criteria or attributes about qualitative and quantitative aspects for improving the accuracy of evaluation results; besides, our proposed hybrid TODIM method can not only express their judgments or linguistic preference with multiple linguistic terms, but also reflect different probability degrees of all the possible linguistic information or preference information. In addition, the concept of entropy and probability linguistic entropy is applied to induce hybrid criteria weight information.

TABLE 5: Sensitivity analysis of the parameter θ

	$\theta = 0.1$	$\theta = 0.3$	$\theta = 0.5$	$\theta = 0.7$	$\theta = 0.9$	$\theta = 1.2$	$\theta = 1.4$	$\theta = 1.6$	$\theta = 1.8$	$\theta = 2.0$
	$\delta(A_i)$	Rank								
A_1	1.0000	1	1.0000	1	1.0000	1	1.0000	1	1.0000	1
A_2	0.1623	4	0.1594	4	0.1567	4	0.1521	4	0.1492	4
A_3	0.4140	3	0.4035	3	0.3940	3	0.3773	3	0.3666	3
A_4	0.5905	2	0.5718	2	0.5548	2	0.5393	2	0.5252	2
A_5	0.0000	5	0.0000	5	0.0000	5	0.0000	5	0.0000	5

6. Conclusions

The frequent occurrence of emergency medical incidents has caused a great deal of property losses and a lot of casualties [17]. Emergency medical management and epidemic situation evaluation has a complex evolutionary process, and emergency decision-making is very difficult to deal with the traditional decision theory. So, in this paper, based on the TODIM method considering the psychology and behavior of the DMs and PLTS expressing preference information of DMs, a hybrid TODIM method with crisp number and PLTS is proposed for aiming to assist DMs to evaluate the severity of urban COVID-19 epidemic situation involved in emergency medical management. Five main advantages of this paper are summarized as follows: firstly, the extended hybrid TODIM method is first proposed for epidemic situation evaluation during a complex humanitarian crisis environment. Secondly, in this hybrid TODIM method, multiple criteria or attributes about qualitative and quantitative aspects are involved, considering the complexity of emergency decision-making process. Thirdly, the proposed hybrid TODIM method can not only express their judgments or linguistic preference with multiple linguistic terms, but also reflect different importance degrees or probability degrees of all the possible linguistic information or preference information. Fourthly, the concept of entropy and probability linguistic entropy is applied to induce hybrid criteria weight information, which has the advantages of simple calculation and clear concept. Finally, sensitivity analysis of the parameter, which considers the psychology factors and cognitive behavior of the DMs, is further carried out on a case study to demonstrate the validity, effectiveness, and stability of the proposed hybrid method for urban epidemic situation evaluation.

The limitations of this work are summarized as follows: epidemic situation evaluation has a complex evolutionary process. Through literature research, based on the complexity of emergency decision-making process, the TODIM method is still not well studied and applied for emergency medical decision-making, although it has done a lot of outreach and extension. So, in this paper, the extended hybrid TODIM method with crisp number and PLTS is first proposed for epidemic situation evaluation. However, the sample size of the data is relatively small.

In future work, new and effective evaluation methods will be further researched and developed by comparative analysis to effectively respond to emergency medical emergencies during a complex humanitarian crisis environment and the crisis response strategies will also be the focus of our research. In addition, big data analysis techniques will also be further developed to reduce the impact of small sample sizes on research results.

Data Availability

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

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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