Emergency Response for COVID-19 Prevention and Control in Urban Rail Transit Based on Case-Based Reasoning Method

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As an important public travel mode, urban rail transit has the characteristics of crowded passengers and closed operation. Safe management of urban rail transit is an important research topic that attracted attention in recent years. This article proposes a decision analysis method based on case-based reasoning, which aims to solve the emergency response problems for the prevention and control of corona virus disease 2019 (COVID-19) in urban rail transit. In this method, first, the historical cases are extracted and filtered by calculating the similarity between the target case and the historical case. A set of similar historical cases is constructed by setting the similarity threshold in advance. Second, comprehensive utility value of emergency response of each similar case is calculated referring to the utility evaluation of emergency response effect and response cost of each similar historical case. On this basis, the emergency plan of the target case is generated by selecting the emergency plans of the similar historical cases corresponding to the maximum comprehensive utility values of the emergency responses. Finally, with the emergency responses of COVID-19 in Tianjin rail transit as the background, this paper explains the feasibility and effectiveness of the proposed method within a case study.

1. Introduction

In recent years, urban rail transit has become an important choice for many large cities in China to solve traffic congestion, alleviate air pollution, and restructure urban space due to its fastness and efficiency, large carrying capacity, energy saving, and environmental protection [1]. Compared with other modes of transportation, the subway has the advantages of large passenger capacity, less pollution, and less impact by weather factors and has gradually become the preferred mode of transportation for people's daily travels [2]. However, because the subway runs below the ground and the internal structure is relatively closed, a large number of passengers often gather in the process of waiting and riding. Therefore, once an infectious public health emergency occurs, it is very easy to cause mutual infection among passengers.

Public health emergencies usually refer to public health events that occur suddenly and may cause serious harms to the society. In recent years, the situation of all kinds of public health events in the world is becoming more and more complex, and the health emergency work is constantly relating to new situations. For example, the severe acute respiratory syndrome coronavirus (SARS) epidemic raged in 2002 and caused thousands of casualties in China [3]. When public health emergencies occur, effective emergency programs must be adopted to minimize the losses. Generally, public health emergencies have the characteristics of sudden occurrence, high uncertainty, and complex evolution situation, which may lead to the lack of effective emergency plan for some specific public health emergencies [4]. In view of this situation, decision makers generally need to refer to the past experience of emergency rescues and generate effective emergency solutions quickly. Therefore, it is a practical and meaningful research topic that, according to some
characteristics and information of the current emergency, how to draw lessons from the emergency responses of historical cases and generate a feasible emergency plan for the current emergency.

At present, the research on this aspect has attracted the attention of some scholars. Amalife and Lu proposed a mobile-based emergency response system, which uses Case-Based Reasoning (CBR) to support emergency decision makers to make emergency responses quickly and effectively [5]. Fan et al. improved the similarity calculation of the CBR case retrieval process and used the improved CBR to formulate emergency plan for mine gas explosion incidents [6]. Based on CBR, Liao et al. proposed generation method of emergency plan for environmental emergencies [7]. Combining CBR and analytic hierarchy process, Kuo developed an intelligent decision support system product recycling and reuse strategies [8]. Most of the existing research results are based on the CBR emergency response method. These researches extract and analyze suitable historical cases by using the CBR to generate the current emergency responses. However, the existing CBR-based emergency response methods rarely involve with the implementation effect and cost of the historical emergency plans. It is possible that extracted historical emergencies may not gain the best effect or even worse, or the selected previous plans may receive the good effect but cause high cost. It should be pointed out that, in view of the actual emergency responses, the generation of emergency plan should not only consider the expected response effect to the emergency, but also think about the cost of the implementation. Then, it is necessary to consider the emergency response effects and costs synthetically when extracting historical cases and generating emergency plan through by CBR [9]. Therefore, for the limitation of the current researches, this paper provides a method of emergency plan generation based on using the decision paradigm of similar historical cases analysis. Firstly, the similarity between the target case and the historical case is calculated, then the historical cases which own the higher similarity than the similarity threshold are extracted, and the effective similar historical case set is constructed by case screening. Based on these, the comprehensive value of the similar historical emergency plans can be assessed through the implementation effect and response cost. Thus, the emergency plan corresponding to the maximum comprehensive value is extracted to be the decision support plan of the current emergency. The main contributions of this paper are as follows. (1) This article establishes a similar historical case set that is compatible with the existing public health emergency management strategy framework and it is more operable for decision makers. It can still provide guidance when decision makers lack relevant experience and expertise. (2) This paper provides a method for generating emergency contingency plans, which considers the implementation effects of similar cases. This method follows the decision-making paradigm based on similar case analysis. Considering the similarity between target case and historical case, this method uses a preset similarity threshold to extract and filter effective similar historical cases and comprehensively evaluate the implementation effects of emergency plans for these historical cases. This method effectively makes up for the shortcomings of the existing CBR-based emergency plan generation method in the extraction and analysis of similar cases, such as the insufficient use of historical data and the lack of consideration of the implementation effect of the plan. Through this method, the emergency plans with the best implementation effect of historical cases can be extracted.

The structure of the remaining parts in this paper is as follows. Section 2 provides a literature review for the relevant research. Section 3 introduces the theory of Case-Based Reasoning. Section 4 researches the generation of the emergency plan for COVID-19 prevention and control in urban rail transit. And Section 5 gives the conclusions.

2. Literature Review

2.1. Research on Emergency Decision-Making. At present, the multiattribute group decision-making of emergency response has attracted wide attention among scholars. For example, some scholars proposed the decision theory and related decision analysis methods based on expected utility theory, and some scholars discussed behavior decision theory and related decision analysis methods based on prospect theory and regret theory [10–12]. Yu and Lai proposed a distance-based group decision-making methodology, which used linear weighting to aggregate information from decision makers and reached a consensus, providing a new idea for unconventional multiattribute emergency group decision-making [13]. Piatsyzek and Karagiannis took the flood emergency rescue activities in southern France as the research object, identified potential risks that may exist during the rescue process, and constructed a complete disaster risk evolution chain based on the interrelationships between risk elements. Finally, combining the local current manpower, technology, and resources, they developed a detailed emergency plan to implement [14]. According to the characteristics of risk emergency activities, Liu et al. analyzed the evolution process of emergency response, expounded the correlation between different elements, and proposed a risk decision-making method based on probability theory and related decision analysis methods based on expected utility theory [15]. For terrorism attacks, Dillon et al. proposed a multiattribute risk decision-making method based on expected utility theory [16]. Aimed at the people evacuation problem after the nuclear leakage accident, Hamalainen et al. constructed group utility function by collecting group opinions; then based on the multiattribute utility theory, the optimal emergency treatment plan was given [17]. Chiou and Lai studied the impact of natural disasters on infrastructure and established an integrated multiobjective model for emergency rescue and traffic control according to the damage situation [18]. Luna and Pennock reviewed the application of social media in the field of emergency management, as well as the benefits and possible risk challenges in the emergency decision-making process [19]. Akter and Simonovic proposed a multiobjective decision-making method based on fuzzy set theory and fuzzy logic for the flood disaster management [20]. Fogli et al. designed an emergency decision-making support
system and proposed an emergency management based on design patterns. The effectiveness of the design pattern has been evaluated by experts [21]. Li et al. take the power system of Liaoning province as an example, and they proposed a novel approach to the determination of optimal opening scheme for electromagnetic loop networks, which was validated in the practical application [22]. Li et al. studied the problem of combined heat and power economic emission dispatch and proposed a two-stage solution methodology by combining multiobjective optimization using the \( \theta \) dominance-based evolutionary algorithm with an integrated decision-making technique of fuzzy C-means clustering and grey relation projection [23].

The existing emergency decision-making research studies mostly assume that the decision maker can estimate the possible results of each option in various natural situation (scenarios) and transform risk or uncertainty into probability. Then, the decision-making analysis paradigm is based on comparing the utility values of a few possible decisions. However, it is not difficult to see that emergencies usually have the characteristics of sudden occurrence, high uncertainty, and complex evolution situations, which may lead to the lack of effective emergency plans or may be difficult to implement the existing emergency plans. Therefore, it is an important research that how to use the historical similar emergency plans to help decision makers to solve the emergency problems during the emergency decision-making process.

2.2. Current Status of Similar Case Studies. In view of how to make the decision with complex characteristics mentioned in the previous section, some scholars have discussed this topic. Some research analyzes from the process by which human beings perceive things. When people recognize new things, they are often accustomed to comparing them with the things already in their mind and deepening their understanding of new things through the comparison. This is also true when making decisions. That is, by analogy, decision makers judge the similarity between the current problem and the historical cases. Based on the analysis of similar cases and the degree of similarity, decision makers speculate the emergency plan. The basic consideration of CBR is that when people face a new problem, they often remind the past similar cases and use the past experience and methods of solving this kind of cases to solve the current problems. Schank and Abelson (1977) first proposed the idea of CBR [24]. For decades, CBR has been widely used in various fields such as medicine [25, 26], manufacturing [8, 27, 28], business [29], tourism [30], and transportation [31], etc. For example, Haque et al. proposed applying CBR to provide decision support methods and techniques for project managers or engineers. They also discussed the case collection, case maintenance, correction, and retrieval through applying CBR [32]. Xiong proposed a new similarity model, which is based on fuzzy rules, to represent the semantic and similarity of the evaluation criteria [33]. Kong et al. used CBR to generate a good solution for adjusting power when the environment changes [34]. Liu and Xi developed a case-based parametric design system to test the turntable [35].

Nowadays, the research of decision-making methods based on similar case analysis is still in the exploratory stage. The existing CBR-based emergency decision-making methods mainly extract similar decision cases according to the characteristics of the cases and solutions. Then, the extracted historical cases may not gain the best emergency response effects or even worse, and the applicability and practicability of CBR decision-making methods is limited.

3. Methodology

3.1. Problem Description. There are two types of the cases when considering the lack of effective emergency plans in emergency responses, including historical cases and target cases. The representation of these cases consists of four parts: emergency problem description, emergency plan description, emergency response effect description, and response cost description. Take \( M = \{1, 2, \ldots, n\} \); \( N = \{1, 2, \ldots, n\} \); \( \Omega = \{1, 2, \ldots, p\} \); and \( \Theta = \{1, 2, \ldots, q\} \). Assume that \( Z = \{Z_1, Z_2, \ldots, Z_m\} \) presents historical case set; \( Z_i \) presents the \( i \)th historical case, \( i \in M \). Assume that \( Z^* \) is the target case; the descriptions of emergency plan, emergency response effect, and response cost of \( Z^* \) are unknown. Generally, the emergency problem involved in historical case \( Z_i \) and target case \( Z^* \) should be described by multiple problem characteristics. Assume that \( C = \{C_1, C_2, \ldots, C_n\} \) is the problem characteristic set of emergency problem; \( C_j \) presents the \( j \)th problem characteristic of the emergency problem, \( j \in N \). Assume that \( \omega = \{\omega_1, \omega_2, \ldots, \omega_n\} \) presents weight vector of emergency problem characteristic. Besides, \( w_j \) presents the weight or the important level of problem characteristic \( C_j \), satisfying \( \sum_{j=1}^{n} \omega_j = 1 \). Assume that \( \bar{z}_i = \{z_{i1}, z_{i2}, \ldots, z_{in}\} \) presents the weight vector of emergency problem characteristic of historical case \( Z_i \); \( \bar{t}_i = \{t_{i1}, t_{i2}, \ldots, t_{in}\} \) presents the weight vector of emergency problem characteristic of target case \( Z^* \). Besides, \( z_{ij} \) and \( t_{ij} \) present the problem characteristic vector of problem characteristic \( C_j \) for historical case \( Z_i \) and target case \( Z^* \) separately. The emergency response effect and response cost of historical case \( Z_i \) are described by \( p \) dimension vector \( \bar{r}_i = \{r_{i1}, r_{i2}, \ldots, r_{ip}\} \) and \( q \) dimension vector \( \bar{e}_i = \{e_{i1}, e_{i2}, \ldots, e_{iq}\} \). Including, \( \bar{r}_i \) presents the emergency response effect describing vector of historical case \( Z_i \); \( r_{ik} \) presents the emergency response effect of \( k \)th aspect of historical case \( Z_i \), \( i \in \Omega \); \( \bar{e}_i \) presents the response cost describing vector of historical case \( Z_i \); \( e_{ik} \) presents the response cost of \( k \)th involved in historical case \( Z_i \), \( k \in \Theta \). According to the actual situation of emergency response, \( z_{ij} \) and \( t_{ij} \) can be divided into two forms: numerical and verbal. In the emergency response to the prevention and control of COVID-19, the problem characteristic value of “infectiousness” is generally numerical; the problem characteristic value of “route of transmission” is generally verbal, which can be expressed as “transmission through air,” “transmission through water,” “transmission through food,” “transmission through contact,” and so on.
3.2. Approach to Emergency Plan Generation. Based on similar historical case analysis, this paper proposes a method of emergency plan generation to solve the above problem. The specific calculation steps are summarized as follows.

3.2.1. Calculate the Similarity between Historical Case and Target Case. K-nearest approach is used to calculate the similarity Sim($Z^*$, $Z_i$) of target case $Z^*$ and historical case $Z_i$. It is calculated through the product of the problem characteristic similarity $\text{Sim}_p(Z^*, Z_i)$ and problem characteristic weight $\omega_j$, which is presented below:

$$\text{Sim}(Z^*, Z_i) = \sum_{j=1}^{n} \text{Sim}_p(Z^*, Z_i) \cdot \omega_j.$$ (1)

Besides, $\text{Sim}(Z^*, Z_i) \in [0, 1]$, the larger $\text{Sim}(Z^*, Z_i)$ presents the higher problem similarity between the emergency target case $Z^*$ and the emergency historical case $Z_i$ and also the higher similarity between target $Z^*$ and historical case $Z_i$ [9].

From formula (1), the calculation of similarity $\text{Sim}(Z^*, Z_i)$ mainly involved the calculation of problem characteristic similarity $\text{Sim}_p(Z^*, Z_i)$. According to the situation of emergencies, this paper divided the problem characteristics into two forms: numerical and verbal. For this two-type problem characteristic, the calculation of problem characteristic similarity $\text{Sim}_p(Z^*, Z_i)$ between target case $Z^*$ and historical case $Z_i$ is given.

When the problem characteristic value of problem characteristic $C_j$ is numerical, the calculation of $\text{Sim}(Z^*, Z_i)$ is

$$\text{Sim}(Z^*, Z_i) = \exp \left( \frac{-|z_{ij} - t_j|}{d_j^{\max} - d_j^{\min}} \right).$$ (2)

Besides,

$$d_j^{\max} = \max\{t_j, \max\{z_{ij} | i \in M\}\},$$
$$d_j^{\min} = \min\{t_j, \min\{z_{ij} | i \in M\}\}.\quad (3)$$

When the problem characteristic value of problem characteristic $C_j$ is verbal, the calculation of $\text{Sim}(Z^*, Z_i)$ is

$$\text{Sim}(Z^*, Z_i) = \begin{cases} 1, & t_j = z_{ij}, \\ 0, & t_j \neq z_{ij}. \end{cases}$$ (4)

3.2.2. Establish Similar Historical Case Set. The extraction of similar historical case should consider the similarity between the historical emergencies and the current emergency, which means the similarity $\text{Sim}(Z^*, Z_i)$ between historical case $Z_i$ and target case $Z^*$.

It is necessary to consider the similarity between historical emergency cases and the current emergency case when extracting similar historical case, that is, the similarity $\text{Sim}(Z^*, Z_i)$ between historical case $Z_i$ and target case $Z^*$. Then, the historical case with high similarity will be extracted as the proper case. Thus, to extract suitable historical cases, similarity threshold value is set. Take $\xi$ as the similarity threshold value between historical case and target case. The calculation formula is presented as follows:

$$\xi = \tau \cdot \max\{\text{Sim}(Z^*, Z_i) | i \in M\}.$$ (5)

Besides, $\tau$ presents the percentage of the maximum similarity between historical case and target case, $0 < \tau \leq 1$; the value of $\tau$ is decided by experience or historical data. The larger value of $\tau$ presents the higher similarity between the extracted historical case and target case [9, 36, 37]. Generally, the meaning of similarity refers to the degree of similarity between two things. In reality, it is not difficult for decision makers to perceive the meaning of similarity. Generally speaking, the range of similarity value is between 0 and 1. The closer this value is to 1, the higher the similarity degree between two things; the closer this value to 0, the lower the similarity degree. If the similarity is 0.9, it means that the decision maker considers that the similarity between two things is 90%. Therefore, about the value range of similarity threshold $\tau$, decision maker can determine it according to the calculation result of the similarity $\text{Sim}(Z^*, Z_i)$, experience, or relevant historical data. When satisfying $\text{Sim}(Z^*, Z_i) \geq \xi$, the corresponding historical case $Z_i$ is extracted. Then similar historical case set $Z^{\text{Sim}}$ is established by extracted historical cases.

$$Z^{\text{Sim}} = \{Z_i | i \in M^{\text{Sim}}\}, \quad M^{\text{Sim}} = \{i | \text{Sim}(Z^*, Z_i) \geq \xi, i \in M\}$$ presents the subscript collection of all similar historical cases.

3.2.3. Calculate the Utility Value of Response Effect and Cost of the Similar Historical Cases. The emergency response effect $r_i^r$ and response cost $e_i^r$ may be numerical and verbal. In order to eliminate the influence of different dimensions on the calculation results, this paper standardizes the emergency response effect $r_i^r$ and response cost $e_i^r$. When $r_i^r$ and $e_i^r$ are both numerical, the standardized formulae are

$$r_i^r = \frac{r_i^r}{r_i^{\max}} \quad i \in M^{\text{Sim}}, \quad r_i^{\max} \in \Omega,$$ (6)

$$e_i^r = \frac{e_i^r}{e_i^{\min}} \quad i \in M^{\text{Sim}}, \quad e_i^{\min} \in \Theta.$$ (7)

Besides, $r_i^{\max} = \max\{r_i^r | i \in M^{\text{Sim}}\}; \quad e_i^{\min} = \min\{e_i^r | i \in M^{\text{Sim}}\}$. When $r_i^r$ and $e_i^r$ are both verbal, the emergency response effect $r_i^r$ and response cost $e_i^r$ of similar historical case $Z_i$ are presented in phrases. Assume the phrase evaluation information set of emergency response effect $r_i^r$ and response cost $e_i^r$ are ordered, take $S = \{S_h | h \in \{1, 2, \ldots, T\}\}$ as the evaluation information set of $T$ phrases. $S_i$ presents the $ith$ phrase of $S$; $T$ is odd number, generally. For example, when $T = 5$, $S = \{S_1: \text{very bad}; S_2: \text{bad}; S_3: \text{common}; S_4: \text{good}; S_5: \text{very good}\}$. Take the subscript serial numbers of verbal emergency response effect $r_i^r$ and response cost $e_i^r$ are seq($r_i^r$) and seq($e_i^r$); then the standardized formulae of $r_i^r$ and $e_i^r$ are
3.2.4. Generate Emergency Plan. The emergency response comprehensive utility $U_i$ of similar historical case $Z_i$ can be gained through the emergency response effect utility $u(r_i)$ and response cost utility $u(e_i)$ of similar historical case $Z_i$; the calculation formula is

$$ U_i = \alpha \cdot u(r_i) + \beta \cdot u(e_i), \quad i \in M^{Sim}. $$

Obviously, the larger $U_i$ presents the better emergency plan of similar historical case $Z_i$. $\alpha$ and $\beta$ present the focus degree of emergency response effect and response cost of decision maker, satisfying $0 \leq \alpha, \beta \leq 1$ and $\alpha + \beta = 1$. Further, according to the value of $U_i$, emergency plans of similar historical case can be ranked, and the best emergency plan of similar historical case can be extracted as the emergency plan of target case $Z^*$. And Figure 1 is shown to describe the process of the proposed method.

4. Case Study

4.1. Problem Description. Corona Virus Disease 2019, referred to as "COVID-19," which means pneumonia caused by 2019 coronavirus infection. Since December 2019, some hospitals in Wuhan, Hubei Province, China, have successively discovered multiple cases of unexplained pneumonia. Most of these patients have a history of exposure to the South China seafood market. Then, this unexplained pneumonia have spread throughout the country and the world. On February 11, 2020, the Director-General of the World Health Organization Tedros announced in Geneva, Switzerland, that the new coronavirus-infected pneumonia was named "COVID-19." "New Coronavirus Infected Pneumonia—Public Protection Guideline" has compiled by Disease Prevention and Control Bureau of National Health Commission of the People’s Republic of China. This guideline proposed that the human-to-human transmission of the new coronavirus is mainly through direct transmission. Direct transmission refers to the droplets of patients who sneezed, coughed, and talked. The exhaled air of patients was directly inhaled through close contact to cause infection. Direct transmission is likely to occur when indoor people gathered, and it is closely related to the methods and effects of indoor natural ventilation and mechanical ventilation.

During this period, the deaths of many patients, including medical staff, caused social panic. For this purpose, the Chinese government have actively carried out related work on epidemic prevention and control. On the one hand, social activities of personnel were controlled to strictly prevent the risks of epidemic import and proliferation. Personnel classification management has been implemented. Residents were classified into three types: high risk, medium risk, and low risk according to the residents’ recent travel history, current health status, close contact history of cases, and other characteristics. Then, targeted control measures were taken. In cities where traffic control was not implemented, personnel were required to be quarantined for 14 days after arriving at the destination. On the other hand, the prevention and control of key sites were important for preventing proliferation risks. Prevention and control responsibilities of community were implemented. Community mobilization played an important role; grid-based, carpet-style management and clear responsibility allocation were implemented. Divisional operations and disperse out-of-peak dining were also implemented. The frequency and scale of meeting were controlled to minimize personnel gathering. The prevention and control responsibilities of institutions were implemented. The opening school date was determined based on the development of the epidemic and the situation of different areas. Students were strictly prohibited from returning to school in advance. The prevention and control of public service places were strengthened, such as farmer’s markets, shopping malls, supermarkets, and other necessities of life and hotels, guest houses, and other life-service places. While promoting the opening of these places, environmental hygiene remediation, disinfection, ventilation, “access inspection,” flow restrictions, and other measures were implemented strictly. Supermarket items were required to be packaged and priced in advance as much as possible, and customers were recommended to self-service shopping to shorten the waiting time in line. Epidemic prevention and control in special places were also strengthened. For the special places such as supervision sites, elderly care institutions, welfare homes, and mental health medical
institutions, it is important to prevent and control the imported epidemics and the spread of internal diseases.

4.2. Emergency Decisions for Prevention and Control of COVID-19 in Tianjin Rail Transit. In order to guarantee the safe operation of rail transit, Tianjin Rail Transit produced emergency plans (target cases) in response to the prevention and control of COVID-19. In this paper, we collected 8 historical cases \( Z_1, Z_2, \ldots, Z_8 \) of public health emergencies in other provinces. Based on the analysis of these cases, five problem characteristics of the cases are determined: infectivity \( (C_{p_1}) \), routes of infection \( (C_{p_2}) \), pathogenicity \( (C_{p_3}) \), propagation distance \( (C_{p_4}) \), and urban population density \( (C_{p_5}) \). The description vector of emergency response effect of historical case is \( \bar{r}_i = (r_{i1}, r_{i2}, r_{i3}) \); besides, \( r_{i1} \) presents the effect of infection control on personnel, \( r_{i2} \) represents the effect of the economic loss control of the rail transit operation department, and \( r_{i3} \) represents the control effect of travel. The description vector of response cost of historical case is \( \bar{e}_i = (e_{i1}, e_{i2}, e_{i3}, e_{i4}) \); besides, \( e_{i1} \) presents personnel costs, \( e_{i2} \) presents the costs of epidemic prevention materials (including purchased masks and disinfectant), \( e_{i3} \) presents direct costs of emergency prevention and control, and \( e_{i4} \) presents time cost of emergency prevention and control. The descriptions of emergency response effect of historical cases are given by verbal information. The phrases evaluation information set is \( S = \{S_1: \text{very bad}, S_2: \text{bad}, S_3: \text{common}, S_4: \text{good}, S_5: \text{very good}\} \).

To conduct an effective emergency plan, following steps applied. Firstly, decision makers invited five experts to evaluate the importance of each index, and the AHP (analytic hierarchy process) weight scale method was used to evaluate the five evaluation indexes. Pairwise comparisons were conducted with the help of a questionnaire survey of experts. A pairwise comparative judgment matrix was then constructed, and the problem characteristic weight vector of COVID-19 was \( w = (0.23, 0.21, 0.31, 0.12, 0.13) \). Then, decision makers decided the case similarity percentage \( \tau = 0.8 \). Finally, according to the phrase evaluation information set, experts scored public health emergency problem characteristics, emergency response effect, and response costs; the scores from experts were combined. Emergency problem characteristics of target cases and historical cases, emergency response effects, and response costs of historical cases were presented in Table 1.

The emergency plan is generated according to the generation method of emergency plan mentioned before. Firstly, according to formula (2) to formula (4), the problem characteristic similarity \( \operatorname{Sim}_j(Z^*, Z_i) \) between target case \( Z^* \) and historical case \( Z_i \), the calculation results are shown in Table 2.
Then, according to formula (1), the similarity Sim($Z^*$, $Z_i$) between target case $Z^*$ and historical case $Z_i$ is calculated as

$$
\text{Sim}(Z^*, Z_i) = 0.72,
$$

$$
\text{Sim}(Z^*, Z_2) = 0.71,
$$

$$
\text{Sim}(Z^*, Z_3) = 0.84,
$$

$$
\text{Sim}(Z^*, Z_4) = 0.89,
$$

$$
\text{Sim}(Z^*, Z_5) = 0.62,
$$

$$
\text{Sim}(Z^*, Z_6) = 0.99,
$$

$$
\text{Sim}(Z^*, Z_7) = 0.66,
$$

$$
\text{Sim}(Z^*, Z_8) = 0.50.
$$

Furthermore, according to formula (5), the similarity threshold value is calculated as $\xi = 0.7923$. Through the set similarity threshold value, the historical cases ($Z_1, Z_3, Z_4, Z_6$) which satisfy the threshold value are extracted. And the similar historical case set is constructed as $Z^\text{sim} = (Z_1, Z_3, Z_4, Z_6)$.

After that, according to formula (6) to formula (11), decision maker takes different risk attitudes, emergency response effects, and response costs in different aspects. Combining the analysis of related historical data, the function of emergency response effect and response cost of similar historical case are given as

$$
u_r(i) = f(r_1^i, r_2^i, r_3^i)
= 0.4r_1^i + 0.33r_2^i + 0.27r_3^i, \quad i \in \{3, 4, 6\},
$$

$$
u_e(i) = g(e_1^i, e_2^i, e_3^i, e_4^i)
= 0.19e_1^i + 0.28e_2^i + 0.21e_3^i + 0.32e_4^i, \quad i \in \{3, 4, 6\}.
$$

Moreover, the utility values of emergency response effect and response cost of similar historical case are calculated as $u_r(Z_1) = 0.946, u_r(Z_2) = 0.812, u_r(Z_3) = 0.826, u_r(Z_4) = 0.723, u_e(Z_1) = 0.547,$ and $u_e(Z_2) = 0.758$.

Finally, according to formula (12) and the real situation of COVID-19 emergency response, when $\alpha$ and $\beta$ take different values, the extracted analysis of emergency plan is described as follows.

When $\alpha = \beta = 0.5$, the decision maker pays the same attention to the emergency response effect and response cost; then $U_3 = 0.835, U_4 = 0.680$, and $U_6 = 0.792$. As the comprehensive utility value $U_3$ is the largest, the emergency plan of similar historical case $Z_3$ is the best.

When $\alpha < 0.5, \beta > 0.5$, the decision maker pays more attention to response cost. For example, if $\alpha = 0.2, \beta = 0.8$, then $U_3 = 0.768, U_4 = 0.600$, and $U_6 = 0.771$. As the comprehensive utility value $U_3$ is the largest, the emergency plan of similar historical case $Z_3$ is the best.

When $\alpha > 0.5, \beta < 0.5$, the decision maker pays more attention to emergency response effect. For example, if $\alpha = 0.8, \beta = 0.2$, then $U_3 = 0.901, U_4 = 0.759$, and $U_6 = 0.812$. As the comprehensive utility value $U_3$ is the largest, the emergency plan of similar historical case $Z_3$ is the best. Particularly, when $\alpha = 1, \beta = 0$, the decision maker deals with current emergencies at all costs. At this point, $U_3 = 0.946, U_4 = 0.812$, and $U_6 = 0.826$. Also, as the comprehensive utility value $U_3$ is the largest, the emergency plan of similar historical case $Z_3$ is the best. Moreover, the emergency response plan of similar historical case with largest comprehensive utility value is extracted as the emergency plan as the target case $Z^*$. It is seen that using the emergency plan generation method mentioned in this article, decision makers can flexibly and effectively select emergency plans to carry out response work based on the actual situation of emergencies.

From the above calculation results, when $\alpha = \beta = 0.5$ and $\alpha > 0.5, \beta < 0.5$, comparing to other similar historical cases, the comprehensive utility value $U_3$ of similar historical case $Z_3$ (SARS prevention and control) is largest. It presents that under urgent and serious epidemic prevention situation,
decision makers are more concerned about the emergency response and will tend to choose the response strategies with good implementation effects. During the SARS prevention and control period, Tianjin Government adopted strict prevention and control measures to strengthen the supervision and management in key traffic stations. For instance, strict entrance control was set at airports, stations, and crossings to measure the passengers’ temperature and make health registration. Also, the sanitation management was strengthened in public gathering places. Various public transportation vehicles and stations were strictly disinfected every day, and workers must wear masks and gloves to work. Central air conditioning was prohibited to use and ventilation was required every day. It is precisely because the government has adopted strong measures, the spread of the epidemic was controlled quickly. But at the same time, during the prevention and control process, strict prevention and control measures also brought higher prevention and control costs. Therefore, when policymakers consider the fact that COVID-19 has a great impact on people’s lives, policymakers will put the protection of people’s lives and health as the top priority consideration. When selecting prevention and control strategies among similar cases, the best case for policymakers is the strategy with good prevention and control effects but high cost. When \( \alpha < 0.5 \), \( \beta > 0.5 \), comparing with other similar historical cases, the comprehensive utility \( U_\alpha \) of similar historical case \( Z_\alpha \) (H1N1 influenza virus) is the largest. It presents that under effective epidemic prevention, decision maker will balance prevention costs and effects. During the prevention and control process of the H1N1 influenza virus, the prevention and control measures adopted by the Tianjin Government were mainly to encourage people to wear masks during their daily travels and avoid gathering in crowded places. At the same time, enough ventilation was guaranteed in stations. Compared with prevention and control measures of SARS, prevention and control costs of H1N1 influenza virus are relatively low. Therefore, combining with similar epidemic prevention and measures in the past, decision makers will choose corresponding prevention and control measures based on the epidemic prevention situation, infectivity, etc.

5. Conclusion

Public health emergency decision-making is a non-procedural real-time uncertainty decision under the conditions of high time pressure, limited human and medical resources, and uncertainty information. At present, there is no unified theory or method to provide a quantitative scientific decision-making model. Based on the analysis of the mechanism of public health decision-making and the essential characteristics of decision-making objects, this paper compares the decision-making of public health events with similar public health events that have occurred and proposes a similar case analysis method for public health decision-making. This method calculates the similarity between target case and historical case. The similar historical case is extracted by setting the similarity threshold. Then, the emergency response effects and response costs involved in the similar historical cases are considered in the emergency plan generation process. The method proposed in this paper is a further expansion of the existing CBR-based emergency response decision-making method. It provides a new idea for solving the problem of generating emergency plan for public health emergencies.

In the future research, two directions have been identified. First, due to the characteristics of public health decision-making, the decision-making process is highly dependent on the experience of decision makers and experts. For example, the determination on the attention degree \( \alpha \) and \( \beta \) of emergency response effects and response costs in this article needs to be further considered. Second, due to the limitations of research conditions and the actual environment, this article only collects and applies limited data or cases for the decision-making of COVID-19. It is necessary to enrich and improve the similar case database in future research, so as to continually improve the practicality and operability of decision-making methods based on similar case analysis.

Data Availability

The numerical application data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

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